Plate 4: Geologic Map of the Potomac Formation in the City of Alexandria, Virginia and Vicinity—Expanded Explanation

By Anthony H. Fleming, 2015

Introduction

The Potomac Formation is a heterogeneous assemblage of early *Cretaceous* river deposits composed of poorly consolidated *sand*, *silt*, and *clay*, along with a much smaller volume of *gravel*. It is the dominant geologic unit in the City of Alexandria (figure 4-1), forming an eroded, wedge-shaped mass of sediment that thickens substantially from west to east. It crops out or is relatively close to the modern land surface everywhere west of Old Town and Del Ray, except in the lower elevations of Holmes Run Gorge in the extreme western section of the city, where it has been stripped off by erosion to expose the underlying *bedrock*. The Potomac Formation attains its greatest thicknesses in the map area (300 - 400+ feet) beneath Old Town and Del Ray, but is covered in that area by thick, late *Pleistocene* *alluvial* deposits of the Potomac River, referred to herein as the Old Town terrace.

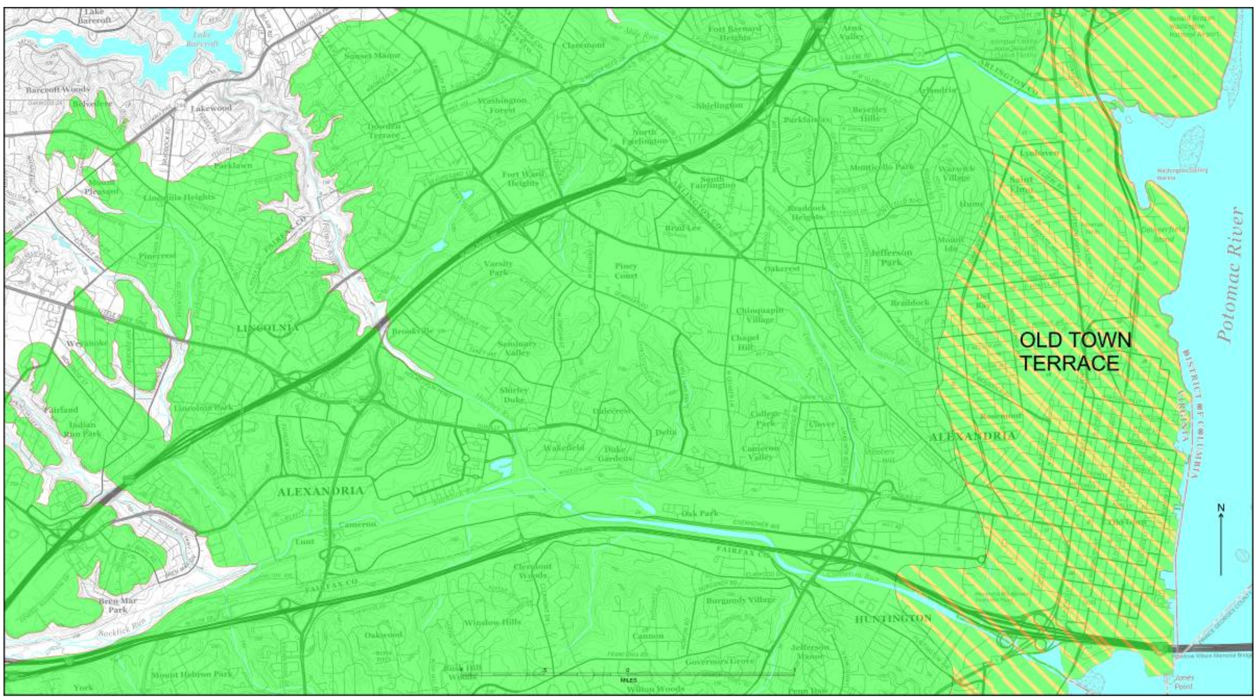

Figure 4-1. The distribution of the Potomac Formation in the map area is indicated in green. It is hidden beneath as much as 125 feet of alluvial deposits of the Old Town terrace (yellow-lined area), but is at or within 30 feet of the surface almost everywhere else.

Plate 4 depicts the geology and structure of the Potomac Formation via a series of informal, geologically- and geographically-defined local units established during this study, and by contours depicting the overall thickness of the formation. These local *members*, or *lithofacies*, provide a three-dimensional framework for understanding the geologic history and physical characteristics of the *formation* in the map area, and for organizing the discussion herein. On plate 4, all of the younger surficial deposits that locally cover the Potomac Formation (see **plate 5**) have been stripped off the map to reveal the distribution and architecture of these local members along the eroded surface that comprises the top of the formation. In many places, the unit that appears on the map does not extend all the way to the base of the formation, and will overlie one or more of the other members. For example, the Cameron Valley sand, which constitutes the base of the formation, appears to be present atop the bedrock surface throughout the city, and is present beneath one or more younger members. The cross sections on **plate 2** illustrate the vertical sequence *stratigraphy* of the Potomac Formation, from its eroded upper surface down to bedrock.

Significance of the Potomac Formation

The Potomac Formation comprises the great bulk of the geologic section above bedrock in the city. It begins as a feather edge in Fairfax County, just beyond the western city limits, and thickens rapidly eastward, exceeding 400 feet in thickness near the waterfront at the southern end of Old Town. The formation continues to thicken east and southeast of the city, and is some 600 feet thick in southeastern Fairfax County (Froelich, 1985) and more than 1,000 feet thick beneath parts of Prince Georges County, MD (Glaser, 1967).

The Potomac Formation is especially important in the highlands of the city west of the Old Town terrace. The rugged *topography* of this section, as well as its overall relief (~280 feet above sea level), is largely developed on Potomac sediments. Differential erosion of contrasting *lithologies* within the Potomac Formation has produced a variety of distinctive landforms (e.g., oversteepened clay bluffs, sand hills) and generated copious volumes of younger surficial sediments (e.g., *colluvium*) throughout the highlands.

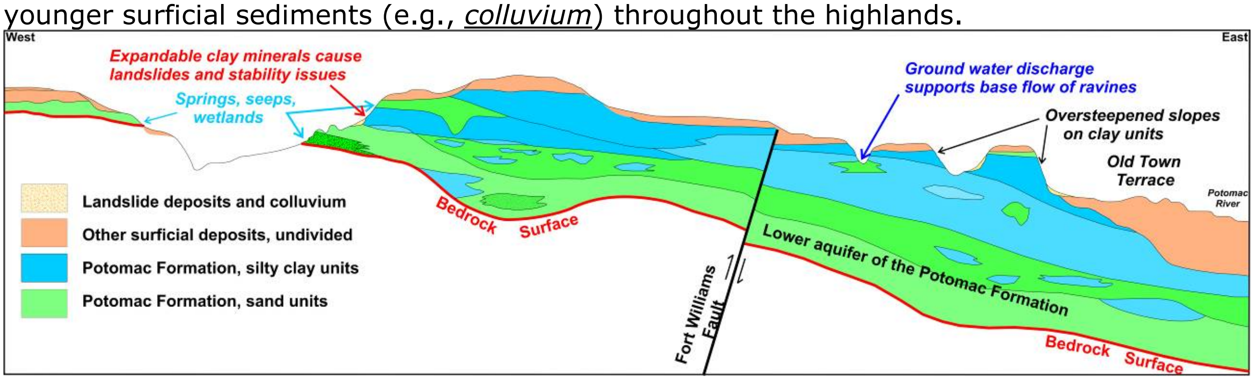

Figure 4-2. Schematic diagram showing the large wedge of Potomac Formation sediments below the city, and some of the significant features associated with it. Not to scale.

The Potomac Formation also is the source of much of the water on and beneath the landscape. Sandy beds give rise to numerous springs and seeps that supply the *base flow* of many streams, ravines, and wetlands, while very large bodies of sand (and some gravel) that make up the base of the formation constitute the principal *aquifer system* throughout the city, and the only one currently proven to be capable of yielding large volumes of potable water to wells. At one time, not that many decades ago, this aquifer system was an important source of water in the city, and someday, it may again be called upon to augment the current water supply from the Potomac River.

From a civil and environmental engineering standpoint, the Potomac Formation is a study in contrasts, consisting of highly varied sediment bodies that possess radically different properties. Historically, so-called "marine clays" (a lingering misnomer) have posed a particular engineering challenge to construction and slope stability because they typically consist of *expandable-lattice clay minerals* that, in combination with abundant fractures and seasonally varied *pore pressures*, commonly lead to slope failures and structural stability issues. Indeed, many major slopes in the city owe their morphology to prehistorical (and, in some cases, ongoing) *landslides* that have been shaping the landscape for thousands of years. Finally, the Potomac Formation, or surficial sediments derived from it, are the substrate for many of the remaining *natural communities* preserved in the city, whose distinctiveness is often directly related to the character of the underlying material and the landforms developed on it.

Previous Studies

There have been numerous studies of the Potomac Formation throughout the mid-Atlantic region since it was first named by McGee (1885) for exposures along the north shore of the Potomac River near Washington, D.C.; this section summarizes only those in the immediate study area. One of the earliest descriptions of the Potomac Formation was by Lester Frank Ward of the U.S. Geological Survey (USGS), who examined the formation throughout the mid-Atlantic region and subdivided it into a variety of units, most of which have since been superceded. His publication "The Potomac Formation" (Ward, 1894) appears to be the first to at least briefly touch on the character of the Potomac Formation within the City of Alexandria: referring to pebbly, arkosic sand of his "Rappahanock Series", Ward noted that "*North of Hunting Creek and Cameron Run, vast quantities of this sand occur in the hills from the river westward for 4 or 5 miles*". Today, this part of the city is locally known as the "sand hills", a name that reflects the sandy soils and protruding hills developed on thick underlying sandy strata of the Cameron Valley sand member in the Seminary Valley, Shirley Duke, and Dalecrest neighborhoods. The same publication also describes Ward's discovery of a species of the fresh-water mussel *Unio* in Chinquapin Hollow, at that time the lowest horizon any shelled fossil organism had been found in the Potomac Formation in Virginia.

During the first half of the 20th century, N.H. Darton of the USGS carried out comprehensive studies and geologic mapping of the Potomac Formation and the underlying bedrock surface throughout the greater Washington region (e.g., Darton, 1947, 1950, 1951; Keith and Darton, 1901). Although Darton made no attempt to subdivide the formation in northern Virginia, many of his observations still stand today and continue to be of great value to modern geologic investigations, including the current study.

Glaser (1969) produced a comprehensive report describing the *lithofacies*, stratigraphy, sedimentary structures, and many other aspects of the Potomac Formation that remains the seminal body of work on the formation in the greater Baltimore-Washington, DC area. Although Glaser's report is focused primarily on the Maryland Coastal Plain, many of his observations are directly relevant to, and can be duplicated within, the present map area.

In the 1970's, the USGS launched a geologic mapping initiative focused on Fairfax County, which resulted in the publication of several 1:24,000 geological maps. These 7.5-minute geological quadrangles, or "GQ's", coincide with the familiar topographic quadrangles of the same names; e.g., Annandale (Drake and Froelich, 1986), Falls Church (Drake and Froelich, 1997), Washington West (Fleming and others, 1994), and several others encompassing nearly all of the jurisdictions surrounding the City of Alexandria. Most of the City of Alexandria lies within the Alexandria 7.5-minute quadrangle, however, which was never published as a separate geologic map. The geology of the Alexandria quadrangle is included at a much reduced scale (1:48,000) in a preliminary geological map of Fairfax County, VA (Drake and others, 1979). On the published GQ's, the Potomac Formation is typically subdivided into two lithofacies: sand and clay, as on the Annandale Quadrangle (Drake and Froelich, 1986) in the far western part of the city. On the 1:48,000 regional compilation, however, the whole of the Potomac Formation within Alexandria City, with limited exceptions, is not differentiated into lithofacies, and is mapped and described only as "varicolored silt and clay, interbedded with sand, pebbly sand, and gravel…".

The USGS mapping initiative led to several other publications on the Potomac Formation, most of which are open-file reports dealing with various aspects of the unit (e.g., ground water availability, slope stability, etc). Two reports of particular value to understanding the geology of the Potomac and its implications for land use in Alexandria include "Folio of geologic and hydrologic maps for land-use planning in the Coastal Plain of Fairfax County, VA, and vicinity" by Froelich (1985) and "Engineering geology and design of slopes for

Cretaceous Potomac deposits in Fairfax County, VA, and vicinity" by Obermeier (1984). The former includes several small-scale maps (scale 1:100,000) showing different aspects of the Potomac Formation, including the percentage of sand in each 100-foot interval of the formation as interpreted from widely scattered borehole and outcrop data. The report also contains many valuable, archival water-level data for the city. However, the basic depiction of areal geology in this publication remains unchanged from the small-scale regional compilation of Drake and others (1979), that is, most of the city is shown as "undivided Potomac Formation". The second publication describes the geologic features, structures, and engineering properties of clays in the Potomac in great detail, and includes chapters by geotechnical engineers that provide practical case studies and observations pertinent to slope stability and foundation issues. Although the publication does not specifically focus on the city, the information it contains is relevant both to current engineering concerns and to an understanding of the geomorphic evolution of the modern landscape.

Age and Environment of Deposition

The *Cretaceous* age of the Potomac Formation was conclusively established by Brenner (1963), who made extensive studies of fossil pollen and spores in the Potomac Group[1] in Maryland. He found that the lower parts of the unit are early Cretaceous, whereas the upper parts are late Cretaceous. The Potomac Formation in Alexandria and adjacent parts of northern Virginia is inferred to be entirely of early Cretaceous age based on regional correlation alone: based on stratigraphic position in the lowest part of the Potomac interval, coupled with important lithologic similarities, the northern Virginia deposits are almost certainly correlative with the lower parts of the Potomac Group in Maryland and DC. Glaser (1969) provides a summary of the regional evidence for the age of the Potomac Formation.

The definitive work on the age of the Potomac Formation within the map area is by Hueber (1982). Working with samples of fine-grained sediments (the Lincolnia silty clay of this atlas) taken from a road cut on Shirley Highway near Winkler Botanical Preserve, Hueber described an assemblage of *microfossils* (pollen, spores. etc.) that closely resembled those described elsewhere from the lower part of the Potomac Formation and clearly indicated an early Cretaceous age. The microfossils specifically indicated deposition during the Barremian-Aptian interval (subdivisions of the Cretaceous, figure 4-3), or about 113-131 million years ago (ma), consistent with early Cretaceous assemblages from elsewhere.

Some of the earliest workers to describe the Potomac Formation in the late 1800's thought it was deposited in an estuary or similar shallow-water, near-shore marine environment, a view based in part on the abundant clays and silts present in parts of the section. This early history probably explains the lingering use of the term "marine clay" to describe the silty clays of the Potomac Formation, a term most often used in connection with landslides and other geotechnical properties of these sediments.

Since then, the discovery of an array of macro- and microfossils in the Potomac Formation has led virtually all geologists since the early 1900's to support a continental origin for the part of the formation west of the modern shoreline. Among the macro fossils, dinosaur remains (found chiefly in clayey facies in Prince Georges and Anne Arundel Counties, Maryland) and tree parts argue strongly for a terrestrial origin. The most persuasive evidence, however, is the distinct assemblages of spores and pollen, which clearly indicate a terrestrial, riverine environment that Brenner (1963) interpreted as a warm-temperate rain forest comparable to parts of modern New Zealand.

[1] In Maryland and DC, the Potomac is considered by geologists to constitute a group composed of three distinct formations: Patuxent Fm (bottom), Arundel Clay, and Patapsco Fm (top). In northern Virginia, these individual formations are not readily recognizable, and the entire Potomac is considered to be of formation rank only. It is referred to as the Potomac Formation in this atlas.

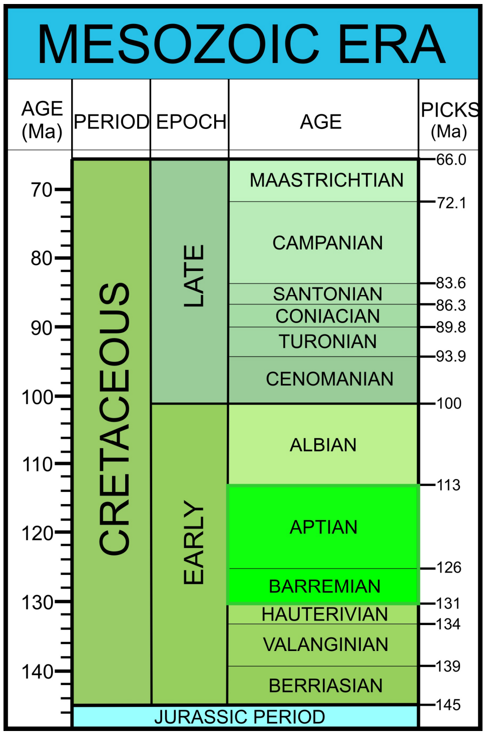

Figure 4-3. Left: Detailed geologic time scale of the Cretaceous Period. The microfossil age of the Potomac Formation in the map area is highlighted in bright green. Ages and picks from the Geological Society of America (2012). Right: Rendering of an early Cretaceous backswamp similar to those represented by some of the Potomac Formation units on plate 4. Courtesy of the Smithsonian Institution.

Similarly, evidence from the current map area unequivocally supports a freshwater, *fluvial* environment of deposition for the entire interval of Potomac Formation exposed in Alexandria. The two most compelling features are the large-scale *facies* architecture of the formation and the sedimentary structures associated with it. Large, wedge-shaped to lenticular bodies of heavily cross bedded sands that follow bedrock valleys and otherwise form channels cut into clayey units are the hallmark of a river system. Moreover, the sands frequently contain conspicuous, large trough cross beds that dip down the strike of lenticular channel fills, and which contain numerous fragments of silty clay, both as isolated *rip ups* and as distinctive clay-clast *breccias*, or *conglomerates*, all features common in river systems. Similarly, silty clay units contain sparse to abundant plant debris, including: cypress needles and trunks, and beds and lenses of lignite, observed during this study; seed cones from pines (Robison and Miller, 1977); fern fragments; other seeds, wood, and cuticles (Hueber, 1982); as well as the aforementioned pollen and spores associated with a terrestrial forest environment. Ward (1894) also described a species of *Unio* (a mussel) from the formation in Chinquapin Hollow, which is an indicator of a fresh-water habitat.

Data Sources and Methods

Data Sources: The previous maps and reports mentioned above acted as sources of background geologic information, while the map in **plate 4** is based mainly on new data collected in and adjacent to the city specifically for this study. Foremost among these new data are: 1) sets of *geotechnical borings* obtained from the city and VDOT for nearly 200 sites in the map area; and 2) numerous observations of the Potomac Formation made in natural outcrops and excavations, concentrated in parts of the city west of the Old Town terrace. The locations of the data used for all aspects of this study are shown on **plate 1**, and the basic information at each site is summarized in the data tables described in the **plate 1 expanded explanation**.

The Potomac Formation is relatively well exposed in outcrops (including many temporary excavations) throughout the highlands of the city (figure 4-4). Although few of the natural exposures are of any great size, they (or the characteristic soils and natural communities developed on the different units within the Potomac) nevertheless are sufficiently numerous to form the backbone of the mapping. They provide the basic visual reference for the formation and its component parts and structures; perhaps more importantly, they allow a reasonable estimation of the internal sedimentary variability (or consistency) at different horizons and locations within the formation. Lithologic and engineering descriptions from more than 2,000 individual geotechnical borings at 190 sites provide the crucial third dimension needed to identify the depth, thickness, lateral continuity, and basic character of the map units defined herein, and their relationships to the major landforms. Data from older water wells collected during previous USGS studies (e.g., Darton, 1950, Johnston, 1961, Froelich, 1985) were less useful to this exercise, primarily because only a few such wells have detailed **formation logs** that describe what lithologies were penetrated at various depth intervals when a well was constructed. On the other hand, the depths and other construction characteristics of nearly all of the wells are known, and since they are typically screened in sand, this information was useful for delineating where, both geographically and vertically in the stratigraphic column, sand bodies are present in the Potomac Formation.

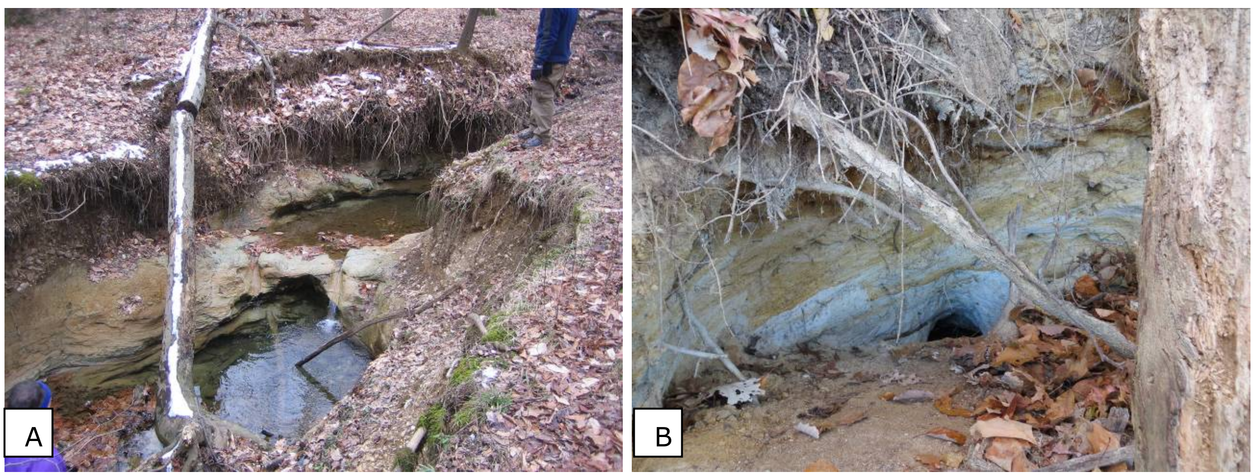

Figure 4-4. Small outcrops of the Potomac Formation abound along ravines (A) in the uplands. Even fox burrows (B) can expose a sufficiently large face to identify and measure sedimentary structures. The old-age white oak-chestnut oak-tulip tree-heath forest in (C) is one of the most distinctive upland natural communities in the city and occurs almost exclusively on sandy units of the Potomac Formation. Photo A by Rod Simmons, B-C by Tony Fleming.

Thickness Contours: The section of the geologic column occupied by the Potomac Formation is bounded by major erosion surfaces known as *unconformities*, each of which represents a hiatus in the geologic record. The base of the formation lies on the bedrock surface, whose configuration is shown on **plate 3**. Since the youngest bedrock in Alexandria is of early *Ordovician* age (roughly 470 ma.), more than 300 million years of "missing" geologic time is represented by the boundary between the bedrock and the base of the Potomac Formation, which is no older than ~131 ma. On the other hand, the top of the formation is bounded by a variety of erosion surfaces that range in age from late *Tertiary* to Recent. These younger erosion surfaces are represented by the bases of several late Tertiary upland river terraces that cap the Alexandria highlands, by the bases of several younger stream terraces lower in the landscape, including the massive late Pleistocene Old Town terrace in the eastern part of the city, and by the modern soil surface in places where the Potomac Formation has been exposed by Pleistocene and Recent erosion. The contours, showing the thickness of the Potomac Formation, known as isopachs, represent the interval between these bounding erosion surfaces, and were derived by taking the difference between the elevation of the modern landscape (or bases of the river terraces, where applicable) and the underlying bedrock surface. The bedrock *topography* shown on plate 3 was fundamental to this process, and to a large extent, the thickness contours shown in plate 4 depend directly on the interpretation of bedrock topography.

Facies Models: Facies models were used to guide the subdivision of the Potomac Formation into the several members and submembers mapped on plate 4. The term "*facies*" has several different connotations in geology, but as applied to the Potomac Formation, it refers to subdivisions of a body of rock or sediment, each having a distinct composition, appearance, set of internal structures, fossil assemblages, and primary geometry that sets them apart from one another. A facies model, on the other hand, is basically a conceptual framework that explains the overall architecture of the different facies that make up part or all of the body of rock or sediment in terms of the depositional environment. Such models are typically based on modern analogs that have been well described in three dimensions, and which can then be applied to the description and interpretation of ancient sediment bodies.

A relatively simple example of this concept is a stack of thick beds of medium to coarse sand containing large (relative to bed thickness) trough *cross beds*, pebbly lenses at their bases, scattered fragments of clayey silt, and perhaps a few pieces of tree trunks. Some sand beds, especially at the top of the sequence, may show planar cross beds, climbing ripples, thin lenses of silt, and other features indicative of a slower or waning current. Such a sequence represents a terrestrial channel facies in a braided stream, and more specifically, a distal, sand-dominated stream that, while relatively far from the source of sediment, was nevertheless choked with sand, producing a broad braid plain that distributary stream channels migrated back and forth across with relative ease, uninhibited by streambanks of cohesive sediment. The main architectural elements in this setting are *longitudinal and transverse bars*, where sand is deposited in the *thalwegs* of migrating stream braids. This facies is well represented in the map area by the Cameron Valley sand member, which lies at the base of the formation and may make up as much as 50% of the total volume of the Potomac Formation in the city. The modern analog for this facies is the Platte River of Colorado and Nebraska, a classic facies model for large, sandy, braided streams (c.f., Smith, 1970; 1971; 1972; Miall, 1977; Blodgett and Stanley, 1980), and a good fit for the sandy lower intervals of the Potomac Formation in the map area.

A slightly more complicated example is a series of strata consisting of repetitive, generally fining-upwards sequences of closely interbedded medium sands, fine muddy sands, silts, and clays; individual sequences are rarely more than a few feet thick (usually much less) and are locally separated by thin beds of lignite or organic silt layers with wood fragments and leaf impressions. In this example, represented in the map area by the Chinquapin Hollow fine sandy clay member, each fining-upwards sequence is characteristic of a single major overbank flood deposit on the surface of a floodplain, probably a very large *point bar*, while the entire group of strata, *in toto*, represents the gradual accretion and eventual abandonment of that point bar. Larger silty clay bodies within the succession of strata represent backswamp deposits filling *oxbows* and swales on or behind the point bar, while larger sand bodies represent features and processes such as *natural levees*, *crevasse splays*, or secondary channels. This kind of *overbank* facies is common to many large modern river systems, but the large scale of this facies in the map area suggests the lower Mississippi River as a viable modern analog, described in a classic series of papers by Fisk (1944; 1947; 1952).

As these examples show, a particular facies may or may not be characterized by any one dominant lithology or grain size. Most sedimentary facies are, in fact, defined by their inherent variability within a specific range of lithologic end members. Stated a bit differently, for some of the members of the Potomac Formation in the map area, it is the nature and scale of lithological variation itself that is of utmost importance not just for defining appropriate map units, but also for understanding the distributions of hydrogeologic, engineering, and ecological properties. Hence, facies models, while imperfect, are nevertheless helpful for understanding and predicting the range of sediment types likely to be present, as well as the general geometries of the various sediment bodies.

Application of facies models to the present study led to the recognition of six main mappable units, or members, in the Potomac Formation in Alexandria, and several other sub-members. Map units were given informal local names to facilitate familiarity and discussion, and to make them more user-friendly for local problem solving. Each member is named for the characteristic lithology present, and for a well-known place in the city where the unit is predominant in the landscape.

For context, it might be noted that attempts to subdivide the Potomac Formation have been problematic in other places, especially in Maryland, where it ranges up to thousands of feet thick and is called the Potomac Group, a term which is perhaps emblematic of greater lithological heterogeneity. As Glaser (1969) points out, abrupt lithological changes are the norm in many parts of the unit, and have not only thwarted efforts to subdivide the group at a local map scale, but even call into question the rationale behind the longstanding subdivision of the group into three large formations.

Three characteristics of the present map area made subdividing the formation feasible:
1) the map area is fairly compact, and contains the relatively thin, updip part of the formation. This results in a comparatively small volume of the formation to deal with;
2) the lithologies in the map area appear fairly consistent and their distribution is understandable in the context of common, time-tested facies models; and
3) the density and quality of data are good in most of the map area. Borehole geophysical logs would have been a welcome addition for correlation purposes, but their absence was compensated by abundant geotechnical borings with understandable descriptions using a consistent set of terminology, while sedimentary characteristics visible in outcrops and excavations provided the necessary context for interpreting the borehole data.

Limitations and Caveats: There are, of course, a number of practical limitations to this approach, most of which would apply to any system of mapping. For example, outcrops are limited in size, geographic distribution, and clarity of the exposure; likewise, sedimentary structures are seldom, if ever, described from engineering boreholes. The nature of the drilling process used in most geotechnical investigations limits the preservation and recognition of such features, even if their description happened to be a goal of the subsurface exploration. Furthermore, the boundaries between different lithofacies are sometimes transitional, or gradational, and may not be displayed prominently in outcrop because the transition typically occurs over distances much greater than the scale of a single exposure. Nevertheless, using a holistic, basin-based approach to visualize past sedimentary environments provides a utilitarian and practical way not only to define map units, but to extrapolate their geometries and boundaries from places where data are robust to areas of limited or less certain information. This technique, broadly referred to as "basin analysis", has been used successfully for decades in the exploration for both petroleum and ground water resources.

More specifically, definition of map units is generally much better in the southern and western parts of the city, where exposures and borehole data are concentrated, and where a readily observable correspondence between map units and landforms is often evident. Some other parts of the map area, however, ranging from relatively small enclaves to quite large tracts, contain sparse outcrops and/or fewer or shallower boreholes, resulting in poor definition of Potomac Formation geology. The distribution of data shown on plate 1 gives a general sense of the reliability of the map.

Two sizable areas are particularly problematic in this regard:
1) the northeastern part of the highlands, generally corresponding to the largely residential area east of Quaker Lane and north of King Street. Most of the area lacks geotechnical boring sites, and the few boring records that are available are shallow, sometimes not penetrating below the base of the younger upland terraces that cap the area. However, there are relatively widespread, if small, outcrops in ravines and on hillsides in the area, which at least makes it possible to make a general determination of the nature of the Potomac Formation and its variability in that part of the city; and
2) nearly the entire area beneath the Old Town terrace, which is blanketed by Pleistocene and Recent alluvium to depths of 50-100 feet or more. There are no outcrops of the Potomac Formation in this area, nor do the majority of geotechnical borings penetrate to the top of the Potomac Formation. Although there are records for many older deep wells in the area, only one of these has a detailed formation log. As many as a dozen deep wells in Old Town were interpreted by Froelich (1985), who gave the percentage of sand in each 100-foot interval, a useful if imprecise metric for understanding the lithofacies of the formation. The source of basic well data upon which these interpretations are based is not clear—none of these wells is reported to have a well log (**Johnston, 1961**), and Froelich did not directly state the basis for the interpretations—but they were taken at face value. Nevertheless, the borehole data do give a sense of the composition of the top of the Potomac Formation at places, and suggest that some of the units mapped in the adjacent highlands continue beneath the Old Town terrace; however, the data are not sufficiently robust to determine the stratigraphy in detail, so most of the Potomac Formation at depth in this area remains poorly known.

Another crucial caveat is that *the map units shown on plate 4 should be regarded as having strictly local significance*. No attempt was made to map the Potomac Formation much beyond the city limits, nor are these map units necessarily expected to extend far into other jurisdictions. The sedimentary environments represented by these units are part of a much larger system that changed through time and space, and it is entirely reasonable to believe that different environments and sediment source areas may have existed in other places at any given time during the deposition of the Potomac Formation. Other workers have noted the sharp differences in clay mineralogy (Force and Moncure, 1978), gravel content in the lower part of the formation (Fleming and others, 1994 vs. this study), and apparent source area of the formation (Glaser, 1969) north and south of Washington, D.C., all of which would seem to imply a significant discontinuity in the formation at the approximate latitude of the modern Potomac River. Although a number of broad trends can be almost universally recognized in the Potomac Formation, on a regional scale the formation is an amalgamation of thousands of different sedimentary bodies, most of which are of local extent and importance. In other words, the units defined herein only have local meaning, and it would be unwise to presume that they are recognizable elsewhere.

Geology of the Potomac Formation

General Observations: Stated simply, the Potomac Formation in the City of Alexandria is the product of a large Piedmont river system whose scale appears to have dwarfed that of the modern Potomac River. Some of the features left by this system are impressively large. The Arell clay, for example, is a massive, wedge-shaped body that appears to fill a rather sizable *oxbow*. Only a fraction of this lacustrine deposit appears to be preserved, suggesting that the abandoned channel it filled could have been well over a mile in width and ten or more miles long. The great lateral and vertical extent of the sandy strata at the base of the formation likewise indicate a very large depositional system. The sedimentary record observed in the city also suggests that the river system evolved over time from a low-sinuousity, relatively higher-gradient situation dominated by sandy facies to a meandering, lower-gradient river in a broad alluvial plain, with a greater proportion of muddy sediment.

Another key aspect of the Potomac Formation that deserves additional emphasis is that, in the Alexandria map area, it is *entirely* of fluvial origin. None of it is "marine" (a persistent misconception that has lingered for many decades, mainly as applied to so-called "marine" clays), nor does the evidence found in this study suggest that any of it is deltaic, estuarine, or even tidally influenced. All of the various sedimentary structures, the lithofacies they occur in, and their geometric relationships to one another can be readily explained as the result of a large terrestrial river system. This interpretation is in keeping with those of other workers, notably Brenner (1963), who found that the pollen assemblages in the formation are indicative of a terrestrial environment of deposition, and Froelich (1985), who was also emphatic about the fluvial origin of the formation in northern Virginia. It is also consistent with the limited fossil evidence available from the city and adjoining areas, all of which points to a fresh-water, riverine origin. In Alexandria, the Potomac Formation might best be described as outwash that originated from erosion of uplands to the west.

Figure 4-5. Overconsolidated Potomac Formation sediments. Left: the type locality of the Cameron Valley sand member is sufficiently compacted and iron-cemented to form a stout ledge, yet can be easily excavated with a trowel. Right: well jointed fine sandy clay, Chinquapin Hollow member. Photos by Rod Simmons.

Still another distinctive characteristic is that all of the Potomac Formation sediments are *overconsolidated* from shallow burial by younger Coastal Plain sediments that have since been stripped off by erosion (figure 4-5). In other words, the hardness of the Potomac Formation is greater than would be expected from its present depth of burial, and is best explained by compaction under the weight of overlying sediments that have since been removed by erosion. None of the formation, however, is systematically lithified into rock, though some sands are weakly to moderately well cemented by purplish-red hematite (so-called "bog iron") and yellowish-orange limonite — iron oxides deposited by chemically-reduced ground water encountering oxygenated conditions as it flows to the surface. Some ledges of the Cameron Valley sand along Holmes Run, for example, are sufficiently indurated that they could be considered as weakly cemented sandstones. Likewise, the major silty clay units are typically very stiff to hard where not softened by weathering—hard enough to sustain extensive fracture systems (fig. 4-5) and to resist penetration by small drilling equipment. Overall, however, the Potomac Formation is not "rock" in anything but a purely *stratigraphic* sense, and is more accurately described as consisting of *unconsolidated sediments*, because it is easily excavated by a pocketknife at most places.

Source Area: Most observers agree that the Piedmont, and probably the Blue Ridge, were the principal source(s) of sediment for the Potomac Formation. This conclusion is based on the abundance and proportions of certain major and accessory minerals, particularly *potassium feldspars* and various heavy minerals derived from Piedmont metamorphic and igneous rocks, such as garnet, staurolite, epidote, and zircon (e.g., McCartan, 1989; Glaser, 1969); it also stems from the abundance of mica, vein quartz, and other lithologies that clearly came from local source rocks.

Certain aspects of the clay mineralogy also suggest a primarily Piedmont source terrain, with the parts of the formation north and south of the Potomac River having different source areas (c.f., Glaser, 1969; Force and Moncure, 1978). The dominant clay minerals north of the river are *illite* and *kaolinite*, whereas *expandable lattice clay minerals* (i.e., montmorillonite) dominate the clay mineralogy south of the river. Force and Moncure (1978) interpreted this difference in clay mineralogy as resulting from regional differences in source area and weathering history, with the northern province reflecting intense weathering of Piedmont metamorphic and granitic rocks under acidic conditions, while the southern province likely reflects weathering of mainly granitic rocks under alkaline conditions. The striking difference in clay mineralogy between the two provinces is accompanied by other important differences in the composition, stratigraphy, and ground-water chemistry of the Potomac Formation (Force and Moncure, 1978). Notably, the sandy beds of the Potomac Formation north of the river are composed principally of quartz, whereas they are mostly *arkose* (feldspar rich) south of the river, a relationship consistent with the idea of a dominantly granitic source terrain for the southern province, because expandable lattice clays are commonly derived from weathering of *felsic* igneous rocks. The Potomac Formation in Alexandria is rich in both feldspar and expandable lattice clay minerals, and thus falls squarely within the southern province of Force and Moncure (1978).

On the other hand, some of the sediment clearly came from further west of the Piedmont: sparse gravelly beds in the Potomac Formation within the map area, as well as the Barcroft diamicton, contain prominent *Skolithos*-bearing quartzites of upper *Cambrian* age from the Blue Ridge (figure 4-6), as well as *clasts* that look very much like *Paleozoic* sandstones from the Valley and Ridge province, an observation also made by Ward (1894).

Cross bed azimuths shown on plate 4 represent paleocurrent vectors and are an indication of local directions of sediment transport. Azimuths in the lower part of the formation almost universally indicate a southeastward direction of sediment transport in the local area. Taken at face value, this suggests a source area to the northwest, but this is probably more indicative of control by local bedrock topography because the azimuths closely parallel nearby bedrock valleys, whose orientations are expected to strongly influence local current directions. Cross bed azimuths higher in the formation tend to indicate an east-northeast direction of current flow, and may be more truly indicative of a source area to the west-southwest, since these horizons are well above any direct influence by bedrock topography.

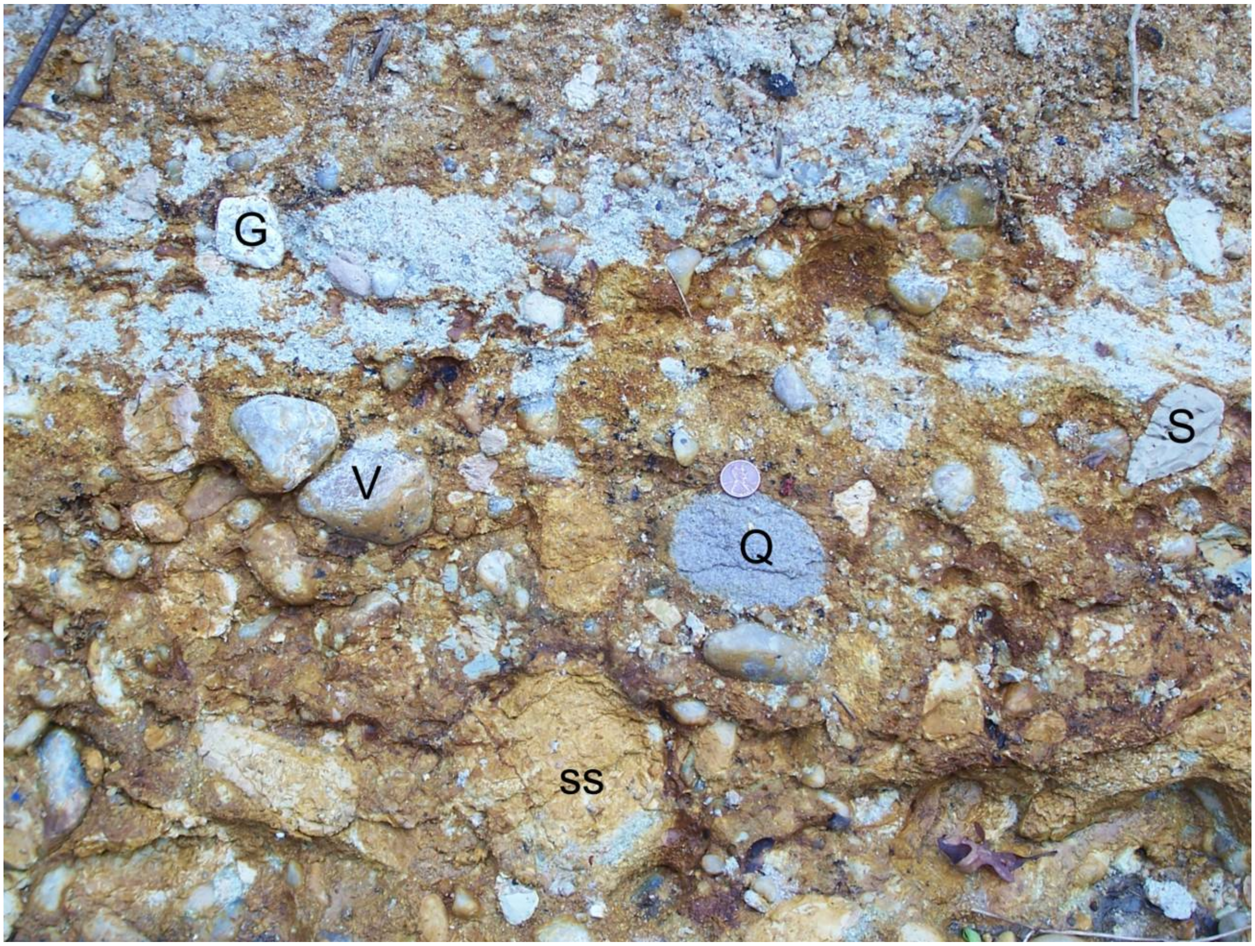

Figure 4-6. Top-Common clast lithologies found in gravel near the base of the Potomac Formation include vein quartz (V), quartzite (Q), various kinds of sandstone (ss), silty-clay (S), and rare granitic rocks (G). Some of the quartzite clasts contain prominent Skolithos burrows (left), a trace fossil common in upper Cambrian Antietam Quartzite from the Blue Ridge. Many of the clasts in this exposure are so weathered they crumble when handled. Width of image on left about 24 inches. Dora Kelley Park. Photos by Tony Fleming.

Lithologies and Map Units: On **Plate 4**, the Potomac Formation is subdivided into six informal local members, or lithofacies. From bottom to top (oldest to youngest), they are:
1) the Cameron Valley sand, a widespread, thick sequence of *arkosic* channel sands, sandy *point bars*, and much lesser fine-grained *overbank deposits* that collectively form the base of the formation everywhere in the map area. This unit is further subdivided into several sub-members, as described later in this chapter;
2) the Lincolnia silty clay, a moderately thick, laterally extensive sequence of silty overbank deposits that probably represent the accretion of a large, distal floodplain atop the coarser-grained Cameron Valley channel deposits. The lower part of this unit contains the unusual Barcroft *diamicton*, composed of a framework of coarse pebbles, cobbles, and boulders distributed in a fine-grained matrix that locally displays soil horizonation and organic layers;
3) the Winkler sand, a group of isolated but locally thick bodies of medium-coarse, locally pebbly, arkosic sand that probably were originally connected as an integrated system of channels incised into the Lincolnia floodplain, but have since become isolated by erosion and truncation across the top of the formation;
4) the Chinquapin Hollow fine sandy clay, a heterogeneous assemblage of fine sands, silts, and sandy clays with abundant plant remains that occur in small, fining-upwards, planar-bedded packages suggestive of deposition in a large, fine- to medium-grained point bar;
5) the Arell clay, an elongate, wedge-shaped deposit of massive lacustrine clay, thought to have been deposited in an *oxbow lake* deposited in an abandoned channel that may have wrapped around the point bar represented by the Chinquapin Hollow member; and
6) the Shooters Hill gravel, an isolated erosional outlier of gravelly arkose that overlies the Arell clay and is probably the remnant of a high-energy bar deposited in a channel.

These members form the basis for the rest of the discussion, and each is described in more detail in subsequent sections of this explanation.

Texture and Clay Mineralogy: Particle size and clay mineralogy analyses were run on 30 samples collected from natural outcrops and excavations, representing all but the Shooters Hill member. Results of the particle size analyses are listed in table 4-1 and presented graphically in figure 4-7.

The Potomac Formation sands in the map area fall mostly into the sandy loam and loamy sand fields in figure 4-7. The silt and clay content is thought to result mainly from post-depositional weathering of feldspars. This is particularly likely for the Cameron Valley sand member. The samples of this unit consist chiefly of medium to coarse sand, while the exposures where they were taken exhibit high-amplitude trough cross beds, scattered small pebbles, and numerous cut-and-fill structures indicative of relatively strong river currents. Thus, relatively little of the silt and clay in the sand is likely to be primary, though in certain places, a small percentage may be attributable to disaggregation of silty clay clasts. Only one sample falls into the sand field on the textural triangle, that being from exposure 42, which exhibits minimal weathering. This low-lying exposure is inferred to have been far below the extent of any Tertiary weathering profiles prior to its relatively recent exhumation by late *Pleistocene* through *Holocene* incision of the Cameron Run drainage.

Clasts of olive to gray silty clay are locally common in the Cameron Valley sand and are presented as a separate category in table 4-1 and figure 4-7. They are composed mainly of silt and were derived from small beds of overbank sediment disrupted by currents.

On the other hand, some of the silt and clay in the Chinquapin Hollow sands could well be primary. These samples are dominated by fine and some medium sand and generally lack the strong current indicators seen in the Cameron Valley member. They are closely interbedded with other fine-textured sediments within sequences thought to represent deposition on a low to moderate energy point bar.

Exposure No.	Map Unit	Field Description	% Gravel	% Sand	% Silt	% Clay
Sand Units						
125-A	Kpch[T]	reddish gray fine clayey sand	-	69	16	14
179-B	Kpch	green brown fine-medium sand	-	80	11	9
183	Kpch	green brown medium-coarse clayey sand	-	70	16	14
33	Kpw	light brown loamy sand	-	50	30	20
38	Kpw	orange-brown medium clayey sand	-	70	15	15
251-A	Kpcv[T]	brown medium-coarse sand	-	85	5	10
154-B	Kpcs	light gray coarse loamy sand	-	57	28	15
153-C	Kpcg	green-brown coarse loamy sand & gravel	54	55	30	15
153-A	Kpcs	light brown med-coarse silty sand	-	83	11	6
42	Kpcs[T]	light brown medium arkosic sand	-	90	6	4
14-A	Kpcs	brown medium micaceous clayey sand	-	80	5	15
12-A	Kpcs	light brown medium micaceous clayey sand	-	84	4	12
Silty-Clay Beds and Clasts in Cameron Valley Sand Member						
12-B	Kpcs	disrupted lens of stiff light gray silt	-	17	62	21
14-B	Kpcs	4" elliptical clast of stiff olive-gray silt	-	16	61	23
153-B	Kpcs	disrupted lens of olive silty clay	-	24	50	26
154-A	Kpcg	lens of hard white clayey silt in gravel	-	24	47	29
251-B	Kpcv[T]	grapefruit-size clast of olive silty clay	-	15	60	25
Silty-Clay Units						
296	Kpa[T]	greenish-gray and brown mottled clay	-	17	22	61
306-A	Kpa	reddish-brown massive clay	-	15	25	60
306-B	Kpa	red-green-gray mottled clay	-	24	27	49
113	Kpa	greenish-gray to yellow-brown sandy clay	-	50	8	41
169	Kpa	very gummy, mottled greenish-brown clay	-	12	30	59
125-B	Kpch[T]	hard red-brown clay loam	-	26	47	27
125-C	Kpch[T]	green-gray-red mottled clay loam	-	31	49	20
179-C	Kpch	reddish-brown silty clay loam	-	21	55	24
179-D	Kpch	reddish-brown silty clay loam	-	9	60	31
179-A	Kpch	orange-green variegated fine sandy clay	-	27	49	23
61	Kpl	deep red-brown silty clay	-	19	45	36
155	Kpl[R]	olive brown clayey silt	-	24	50	25
78	Kpb	gray-brown gravelly loam diamicton	18	33	47	20

Table 4-1. Particle size distributions of Potomac Formation map units. In the two gravelly samples, sand-silt-clay values reflect their relative proportions in the matrix, while the gravel values reflect the proportion of gravel in the total sample volume. T- type locality of member; R-reference section.

Detailed *petrographic* studies of the Potomac Formation were not made for this project, though qualitative examination of numerous outcrops and samples were made under magnification and natural light. The sands appear to have originally been *lithic* arkoses and arkosic *quartz arenites*, but subsequent weathering of the feldspar has resulted in the development of considerable *diagenetic* silt and clay, which partially fill the interstices between the remaining sand grains. The presence of appreciable silt and clay is a pervasive characteristic of Potomac Formation sands throughout the map area, and typically imparts a dense, stiff consistency that causes them to stand up in steep banks, ledges, and bluffs.

The silty clay units sampled for this analysis range from slightly to moderately sandy. _Clay_ predominates the fine fraction of samples of the Arell clay, while _silt_ is the dominant size fraction in the Lincolnia silty clay and Chinquapin Hollow fine sandy clay members. Most of the sand in all of these units is in the _fine to very fine sand_ range.

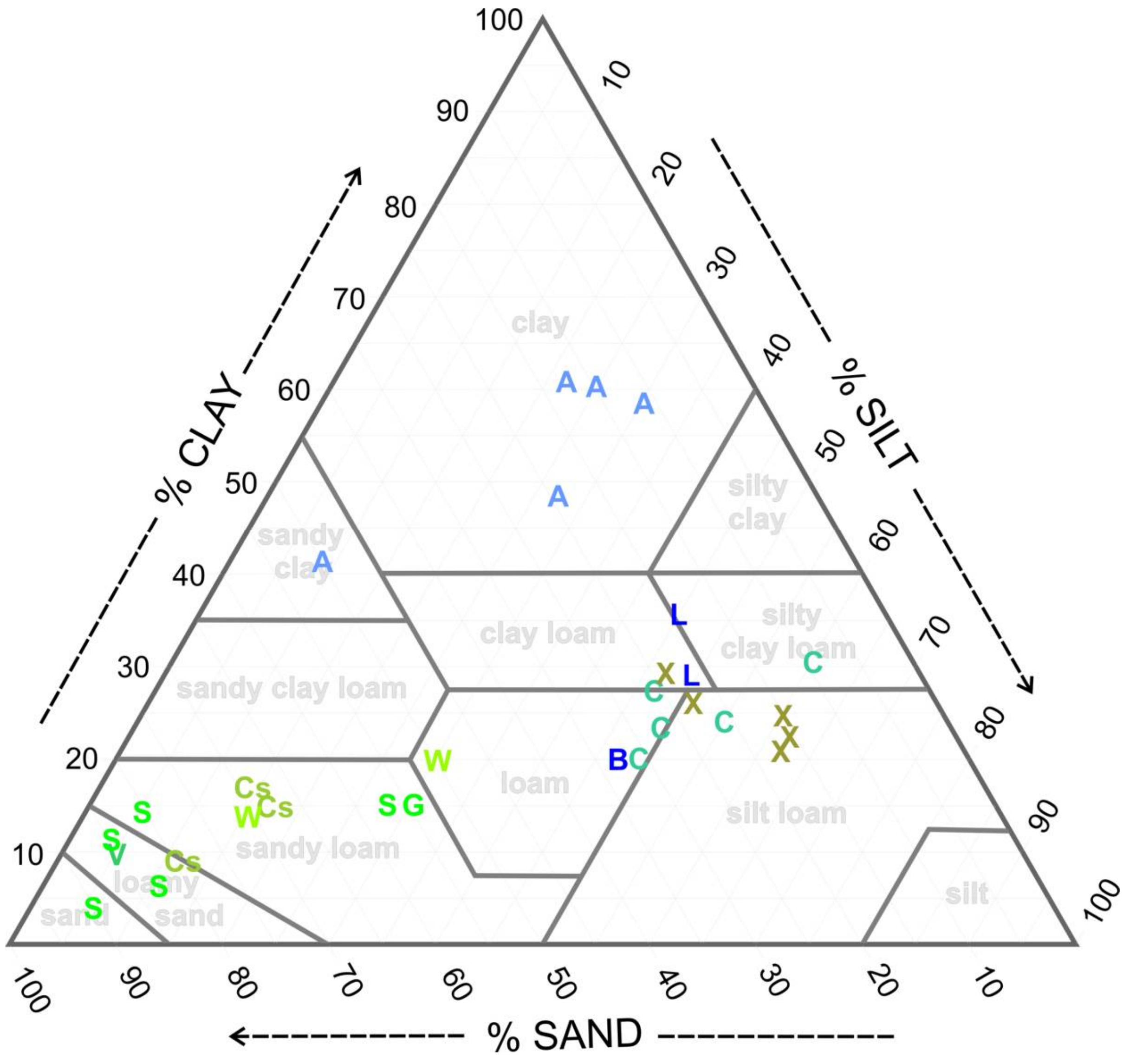

Figure 4-7. Particle size distribution of Potomac Formation map units depicted graphically on the USDA textural triangle. See Soil Survey Staff (1999) for description of textural fields. Symbols are: A-Arell clay; B-Barcroft diamicton; C-Chinquapin Hollow fine sandy clay; Cs-sand bodies in the Chinquapin Hollow member; G-Cameron Valley sand, gravel facies; L-Lincolnia silty clay; S-lower Cameron Valley sand; V-upper Cameron Valley sand; W-Winkler sand; X-silty clay clasts and disrupted beds in the Cameron Valley sand.

The Potomac Formation in Alexandria is strongly dominated by *expandable-lattice (high shrink-swell) clay minerals* (table 4-2), and belongs to the southern montmorillonite[2] facies as used by Glaser (1969), Force and Moncure (1978), and Obermeier (1984). This contrasts with the predominantly *illite*- and *kaolinite*-rich lithologies found north of the Potomac River, and implies a different source area. Glaser (1969) and Force and Moncure (1978) suggested the montmorillonite facies could have been derived from a weathered granitic source rock terrain (such as the Blue Ridge) southwest of the map area.

Exposure No.	Map Unit	Expandable Clays	Illite	Kaolinite	Chlorite	Vermiculite Index
Sand Units						
125-A	Kpch[T]	88%	9%	1%	1%	4
179-B	Kpch	92%	6%	1%	1%	2
183	Kpch	73%	6%	11%	10%	32
33	Kpw	21%	15%	43%	21%	13
38	Kpw	1%	11%	55%	33%	31
251-A	Kpcv[T]	95%	3%	1%	1%	2
154-B	Kpcs	89%	5%	2%	4%	6
153-C	Kpcg	80%	2%	15%	4%	9.5
153-A	Kpcs	72%	6%	15%	6%	2
42	Kpcs[T]	59%	14%	12%	15%	21
14-A	Kpcs	65%	14%	8%	12%	-2
12-A	Kpcs	68%	9%	19%	4%	-2
Silty-Clay Beds and Clasts in Cameron Valley Sand Member						
12-B	Kpcs	47%	29%	17%	7%	-9
14-B	Kpcs	84%	7%	5%	4%	12
153-B	Kpcs	85%	9%	4%	3%	5
154-A	Kpcg	68%	11%	15%	7%	9
251-B	Kpcv[T]	69%	27%	2%	2%	-2
Silty-Clay Units						
296	Kpa[T]	81%	4%	8%	6%	23.5
306-A	Kpa	11%	7%	52%	30%	42
306-B	Kpa	31%	9%	36%	23%	57
113	Kpa	68%	10%	12%	11%	25
169	Kpa	29%	12%	35%	24%	74
125-B	Kpch[T]	93%	3%	2%	2%	8
125-C	Kpch[T]	96%	2%	1%	1%	10
179-C	Kpch	93%	4%	1%	1%	7
179-D	Kpch	96%	2%	1%	1%	4
179-A	Kpch	95%	4%	1%	1%	6
61	Kpl	2%	3%	61%	35%	24
155	Kpl[R]	78%	11%	7%	4%	9
78	Kpb	14%	9%	48%	30%	26

Table 4-2. Clay mineralogy of the Potomac Formation in Alexandria. T-type section of member; R-reference section

[2] Montmorillonite and smectite are other commonly used terms for expandable lattice clay minerals that have appeared in the literature concerning the Potomac Formation in northern Virginia.

The predominance of expandable-lattice clays is graphically illustrated by the ternary plot in figure 4-8. The overwhelming majority of samples plot squarely within the montmorillonite facies as depicted in Force and Moncure's (1978) figure 3. The other samples contain increasing amounts of kaolinite at the expense of expandables, reflecting the loss of calcium and sodium during weathering. This effect is most pronounced in the trend of the data for the Arell clay (A), in which increasingly weathered samples contain progressively more kaolinite. The same process is responsible for the vast difference between the two samples of Lincolnia silty clay, and for the relatively high kaolinite content of both Winkler sand samples. With the exception of the Barcroft diamicton, all of the samples in the lower part of the plot came from places relatively high in the landscape with strong weathering profiles.

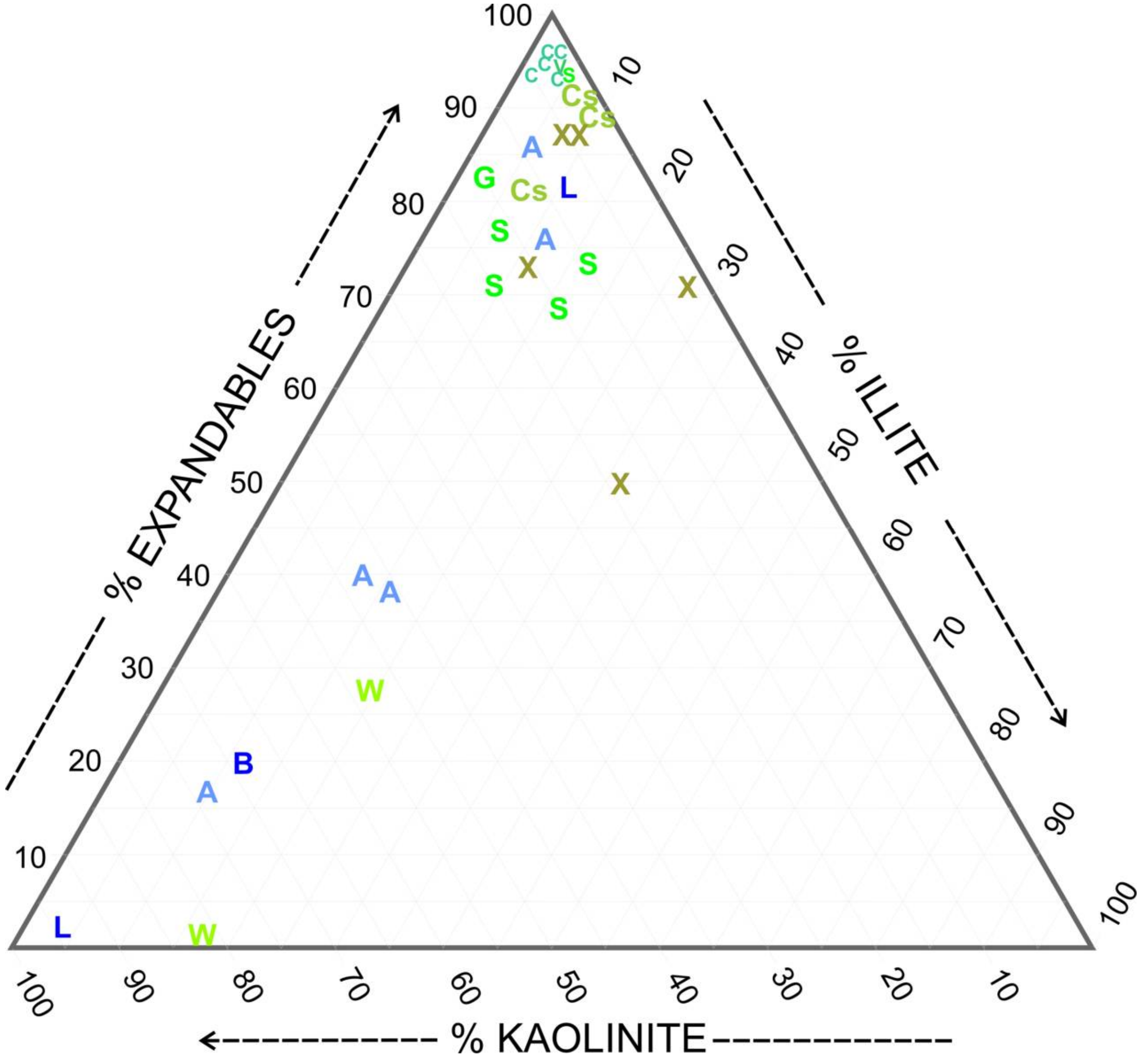

Figure 4-8. Relative proportions of illite, kaolinite, and expandable clay minerals in Potomac Formation map units. Symbols are: A-Arell clay; B-Barcroft diamicton; C-Chinquapin Hollow fine sandy clay; Cs-sand bodies in the Chinquapin Hollow member; G-Cameron Valley sand, gravel facies; L-Lincolnia silty clay; S-Cameron Valley sand, lower unit; V-Cameron Valley sand, upper unit; W-Winkler sand; X-silty clay clasts and disrupted beds in the Cameron Valley sand.

<u>Cameron Valley sand (**Kpcs, Kpcg, Kpcc, Kpcv**)</u>: This member makes up the lower part of the Potomac Formation everywhere in the map area. It crops out extensively along the north side of the Cameron, Backlick, and lower Holmes Run Valleys, where it underlies the "sand hills" of Ward (1894), a distinctive region of low, sandy hills and ridges surrounded by younger fan and stream deposits centered on Dalecrest and Seminary Valley. Johnston and Froelich (1977) also showed a major sand body paralleling Cameron Run. It is also well exposed at places along the south side of Four Mile Run between Shirley Highway and Barcroft Park in southern Arlington County, where it forms large bluffs bordering the valley bottom. The type locality is a ledge (exposure 42, **plate 1**) about 200 feet long on the north side of Backlick Run just below the low-head dam at Ben Brenman Park.

The Cameron Valley sand thickens dramatically eastward across the map area, from just a thin feather edge in the far west, where it is truncated by erosion, to more than 200 feet near Quaker Lane and Four Mile Run, and near Wheeler and Duke Streets in the Cameron Valley. Some of the thinning and thickening is the result of post-Cretaceous tilting and erosion (e.g., the thin eroded western edge), but some is original: the observed thickness of the unit beneath the Lincolnia silty clay member ranges from less than 50 feet to nearly 200 feet. The thickness of the Cameron Valley sand shows a strong correspondence to the Cameron and Four Mile Run bedrock valley systems (**plate 3**), with the thickest known sections occurring over the thalwegs of the bedrock valleys.

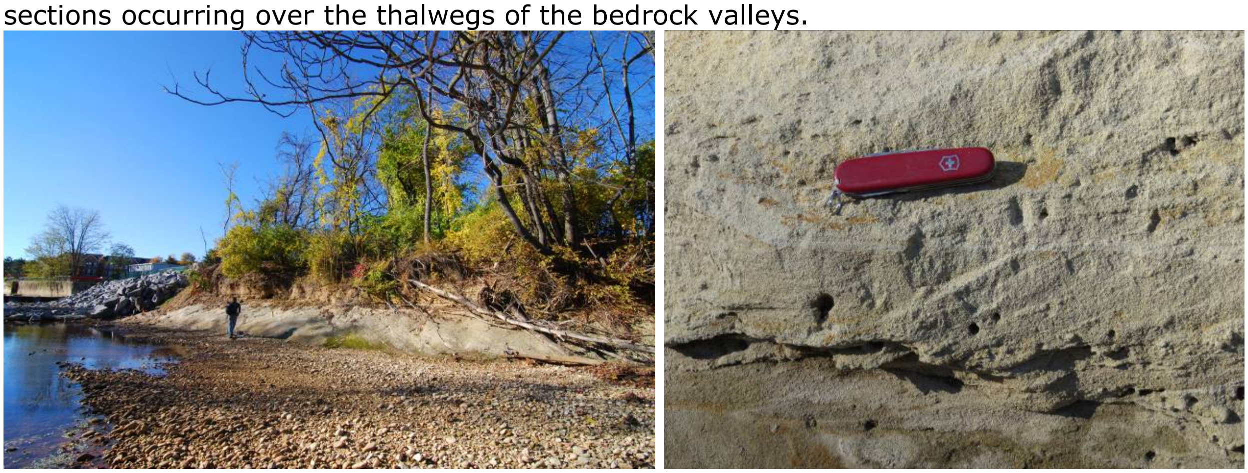

Figure 4-9. The type locality of the Cameron Valley sand (left), displaying the light brown, cross-bedded, medium sand (right) typical of the unit. This outcrop, and others in the same area, have only recently been exhumed by stream erosion and are minimally weathered, allowing the primary texture and structures of the sand to be seen to advantage. Unfortunately, as often happens in urban settings, a key part of the outcrop was recently destroyed and now resides beneath the imported rip rap visible in the background. Photos by Rod Simmons (left) and Tony Fleming (right).

Four sub-members are recognized, though precise boundaries between them are generally difficult to define. The lower part of the Cameron Valley sand (map unit **Kpcs**) consists almost entirely of clayey, medium, arkosic sand dominated by medium- to large-scale trough *<u>cross beds</u>* (figure 4-10). Close to the bedrock surface, the unit is commonly micaceous. Some beds consist of coarse sand, but the unit is seldom gravelly, except for scattered pebbles at the base of some cross bed sets, which probably represent a lag deposit. The predominant cross-bed dips observed in numerous outcrops indicate an east to southeast direction of stream transport, which suggests that individual sand bodies are likely to be elongated in the same direction. Only a few exposures are sufficiently tall to expose the full heights of the sets. The largest cross beds observed are about 6 feet tall, though most appear to be less. Many beds exhibit a lenticular profile in cross section.

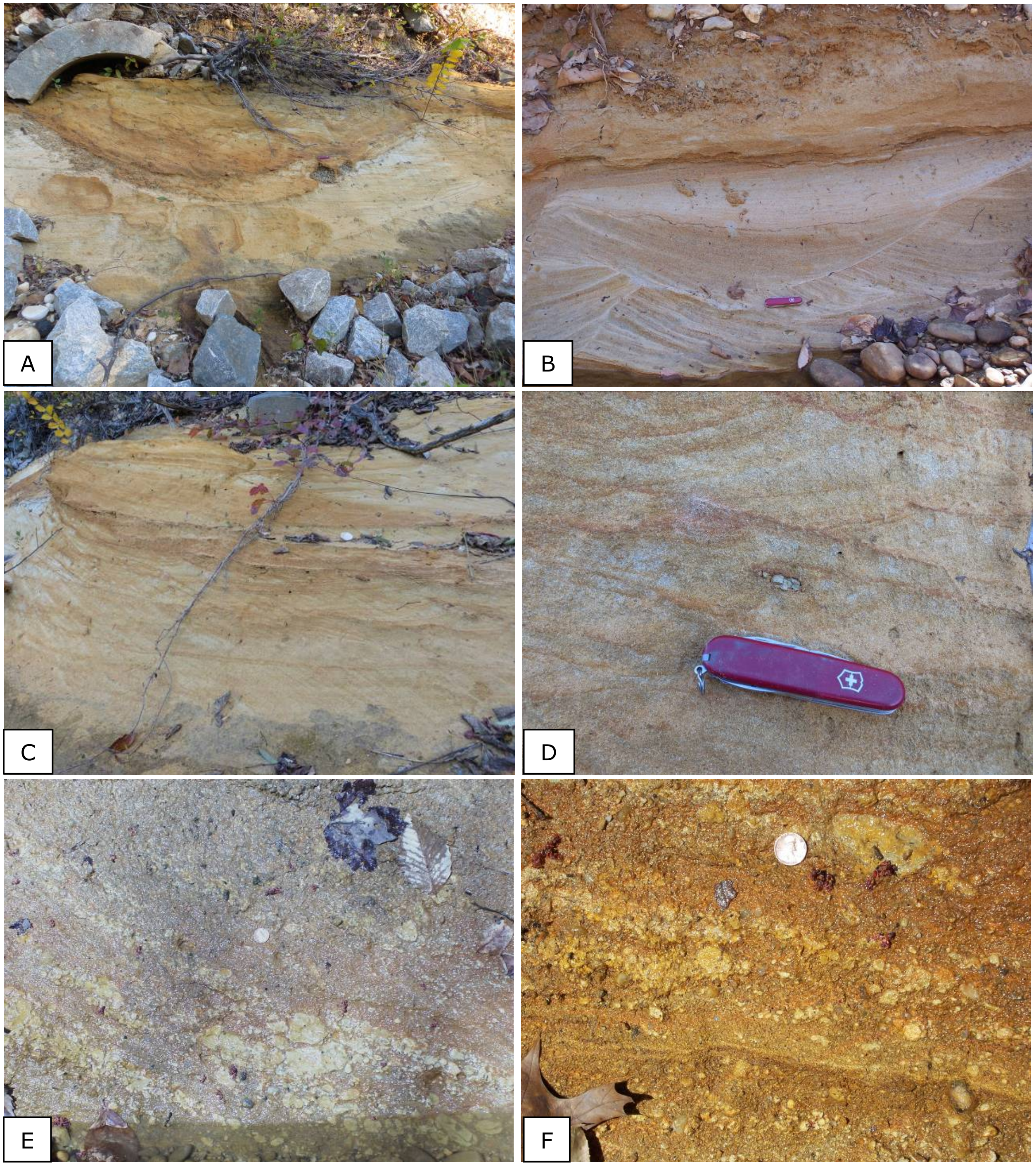

Figure 4-10. Trough cross bedded sands with many cut-and-fill structures (A-B) dominate the lower Cameron Valley sand member. Planar beds (C-D) occur much less commonly. Isolated clasts composed mainly of silt (table 4-1) are common and include large, rounded masses like the two gray objects below the knife in (A), and the tiny chip above the knife in (D). Less commonly, the clasts form "conglomerates" (E-F) that often appear along ill-defined horizons and in which the edges of adjacent clasts appear to fit together, suggesting dismemberment of thin beds of overbank sediment. Photos by Tony Fleming.

Some beds in the lower Cameron Valley sand contain clasts of greenish gray clayey silt, which range from tiny chips and rounded balls to large slabs up to 3 feet in length, and are frequently concentrated along the bases of troughs (e.g., figure 4-10A). Localized "clay clast *conglomerates*" (or *breccias*, figure 4-10E-F) composed of rounded to angular silt-clay fragments can be seen to emanate from thin, disrupted beds of the same. The silt beds look like drapes deposited during periods of waning current flow. There were probably more such beds deposited, but few are likely to have been preserved in this relatively energetic sedimentary regime, and their remains are now represented by fragments in sand beds.

Excellent examples of map unit Kpcs can be seen in the many large ledges that extend downstream along Holmes Run from the bedrock overlap at Paxton Street to the Backlick Run confluence. Other examples occur on the hillsides and ravines above Holmes Run Gorge and at scattered locations in Four Mile Run Valley. Many of these outcrops exhibit various weathering phenomena involving the translocation of iron (figure 4-11) that frequently accentuate original sedimentary structures.

Figure 4-11. The migration of iron "fronts" is an important process in during weathering and ground-water discharge in Potomac Formation sands. In the outcrop on the left, rusty, iron-rich bands accentuate the chaotic bedding produced by soft-sediment deformation that occurred shortly after the sand was deposited. The same process commonly leads to ferruginous concretions (right). Photos by Tony Fleming (left) and Rod Simmons (right).

A gravelly variant (map unit **Kpcg**) makes up another of the Cameron Valley submembers. It occurs at scattered places along and near the base of the formation, and consists of fine to medium sandy gravel and gravelly sand in beds up to 6 feet thick, commonly interbedded with generally thinner lenses of white to olive sandy and clayey silt. The thinnest clay beds are commonly disrupted, and the granular units frequently contain many clay clasts (figure 4-12). The gravel is typically disorganized and poorly sorted; in a few places, cobble and boulder beds embedded in silty clay are present. Some beds are better sorted than others, and a few of the sandiest exhibit a vague planar cross stratification.

This unit is typically found in close proximity to the bedrock surface, where the dominant type of gravel consists of frosted vein quartz derived from local Piedmont bedrock. Other types of local Piedmont bedrock are also common, as are *Skolithos*-bearing sandstones and quartzites from the Blue Ridge (see figure 4-6). Some of the gravel may have accumulated close to an original valley wall or in the lees of bedrock obstructions, where highly angular clasts of local bedrock may have originated nearby as colluvium or rock falls. Gravelly beds are also reported at higher positions in the Cameron Valley sand in some geotechnical borings, but are rarely large enough to map. The largest composite thickness of gravelly beds known is about 30 feet, along lower Holmes Run. Good examples of this map unit can be seen along Four Mile Run at Barcroft Park in southern Arlington County (exposures 87-89), along both sides of Holmes Run below the Paxton Street low dam (exposure 14), and in a ravine below North Chambliss Street in Dora Kelley Park (exposures 153-154).

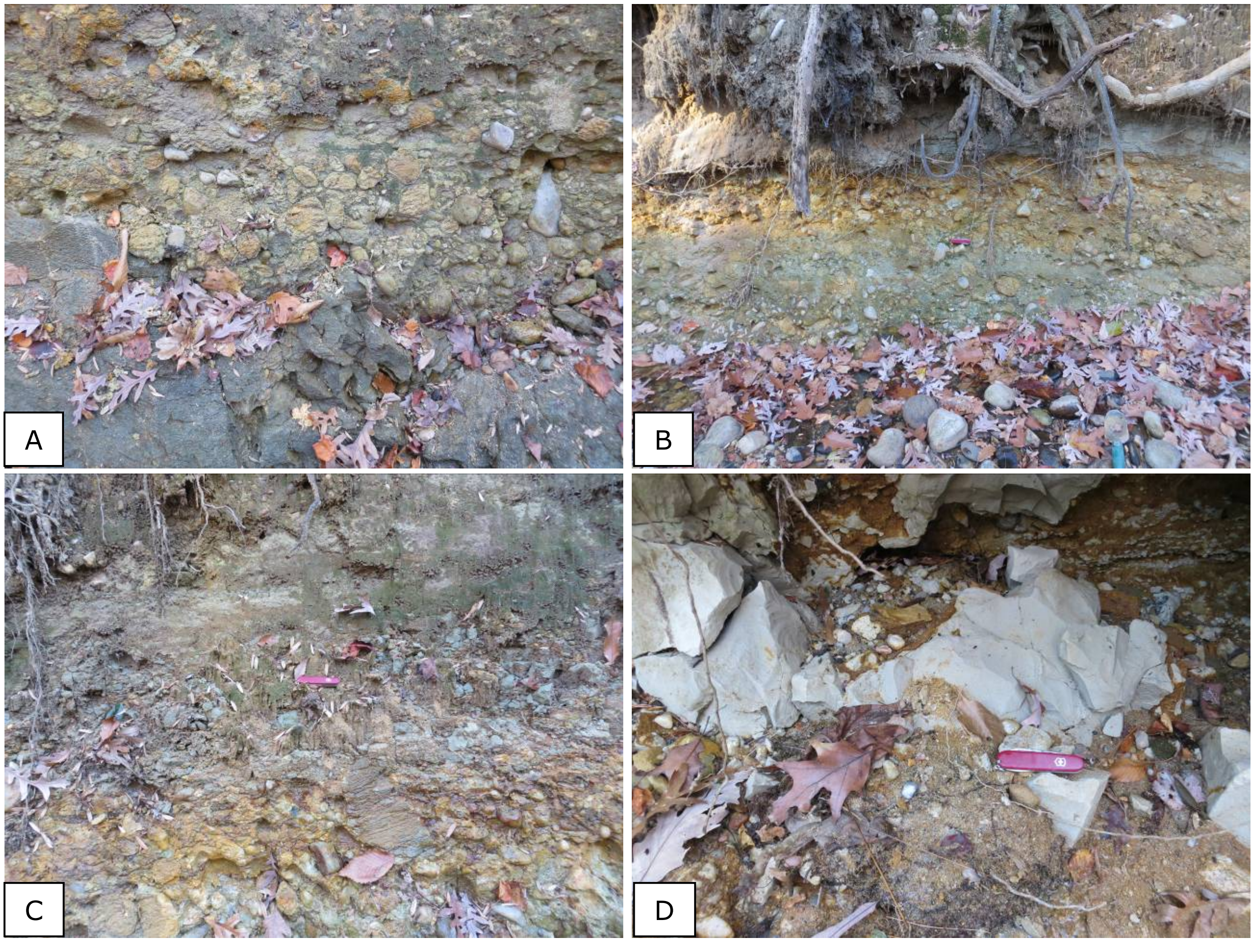

Figure 4-12. (A) Disorganized gravel overlying an irregular bedrock surface on the Indian Run Formation contains clasts of the Indian Run Formation and Occoquon Granite, as well as angular vein quartz fragments that have experienced minimal stream transport and rounding. Greenish gray silt (B) beneath the tree roots is draped over the gravel below. The gravel shown in (C) is located about 15 feet laterally from (B) and is choked with fragments from the same green-gray silt body. Small lenses of distinctive whitish silt (D) are locally associated with gravel bodies near the base of the Potomac Formation, and often terminate in "clay clast conglomerates" (visible in the upper right quadrant). Photos by Tony Fleming.

A third sub-member, represented by map unit **Kpcc**, consists of map-scale plugs of green-gray silt and silty clay. This unit is not well exposed in the city and is known almost entirely from geotechnical borings in the Cameron and Four Mile Run bedrock valleys and their tributaries (see **plate 3**). A particularly thick and extensive body occupies the north side of the modern Four Mile Run valley in the vicinity of Shirley Highway (GTB sites 66-67), while other bodies are defined by borings along the Capital Beltway west of Telegraph Road and near Cameron Regional Park, respectively. Other similar bodies are likely present elsewhere in the city, but remain undetected.

Some of the larger silty clay bodies beneath the Cameron Valley appear to occupy the interval where the Lincolnia silty clay is found further to the west. The same may be true in the vicinity of Four Mile Run. Although subsurface data in those areas are too sparse to determine whether a direct connection exists, the map pattern strongly suggests that the Lincolnia is in a lateral facies relationship to the Cameron Valley sand. It is worth noting the similarities in texture (figure 4-7) and clay mineralogy (4-8) between the Lincolnia silty clay and the silt clasts and disrupted beds elsewhere in the Cameron Valley sand. Thus, it is tempting to think that some bodies of unit Kpcc represent the extension of a thinner and more discontinuous Lincolnia unit into the dominantly sandy upper Cameron Run sediments overlying the major bedrock valleys.

Map unit **Kpcv** makes up the upper part of the Cameron Valley sand. This unit is best developed in and near the Cameron and Four Mile Run bedrock valley systems; it consists of large masses of cross-bedded sand similar to unit Kpcs, but locally contains more and larger interbedded silty clay units, particularly in higher parts of the section. Coarse sand is a prominent constituent in some exposures and borings. Good exposures of medium to coarse sands with large trough cross beds occur along Duke Street (exposures 5, 41), Wheeler Street (exposures 1, 24), and at Fort Williams Park (exposures 251, 298, the type locality for the upper unit; figure 4-13). Above Four Mile Run, similar sands are reported from the geotechnical borings around the Shirley Highway x Quaker Lane interchange, and could be inferred from slumped exposures on the lower hillsides along Valley Drive in Parkfairfax (exposure #53) and in Shirlington, where distinctive remnants of old age "sand forest" (figure 4-4) dot the bluff.

Figure 4-13. The upper Cameron Valley sand at Fort Williams Park crops out in stout ledges featuring steeply dipping cross beds (A-B). Isolated silt clasts, such as the well-rounded, greenish, softball-sized one in (C), are fairly common throughout the unit. Here, the clast is accompanied by a few rounded quartz pebbles. The sand in the unit falls in the medium to coarse range (D). Photos A-B-C by Tony Fleming; D by Rod Simmons.

Like the lower unit, cross beds in the upper Cameron Valley sand are mainly of the trough variety, and foresets consistently dip to the east-southeast, suggesting sediment transport from a source to the west-northwest. The major exception is at Fort Williams, where cross bed vectors are oriented west-northwest, but the entire section at that site appears to be deformed by faulting (see the **Fault Catalog in Part 8**) and is tilted westward by as much as 12 degrees, complicating interpretation of cross-bed azimuths.

The boundary between the upper and lower units of the Cameron Valley sand is difficult to define, because no distinctive horizon (such as a persistent silty clay unit) or other stratigraphic marker is consistently present between them. Moreover, fine-grained material is not always present in the upper unit, and composite sections of sand in excess of 200 feet thick may be present over some parts of the major bedrock valleys. Where possible, the boundary between units Kpcs and Kpcv is drawn where nearby outcrops or borings indicate an upward increase in the volume of fine-grained sediment in the section; elsewhere, it is arbitrarily defined by the 100-foot thickness contour. In this part of northern Virginia, the Cameron Valley sand generally corresponds to what has been described as the "lower aquifer" of the Potomac Formation (e.g., Johnston and Larson, 1977; Froelich, 1985).

Collectively, the Cameron Valley sand member appears to record the establishment, alluviation, and eventual abandonment of a major channel system. The thickest sections are coincident with the Cameron and Four Mile Run bedrock valleys, indicating that channels initially established in the thalwegs of these valleys may have persisted in the same general area once the bedrock valleys were filled. The sedimentary structures, lenticular bedding, and consistent texture indicate map unit Kpcs was likely deposited in longitudinal and transverse bars in the channels of a large, moderate-energy river system of low sinuousity. The paucity of interbedded fine-grained sediment in this unit, together with the high-amplitude trough cross beds that consistently point down the gradient of the bedrock valleys and the bedrock surface generally, imply that the system was choked with sand and lacked well-defined riverbanks. An expansive braid plain similar to the modern Platte River and other streams draining the High Plains fits the widespread distribution and consistent sedimentary characteristics of the unit.

The upper part of the Cameron Valley sand is also interpreted to have formed in the same environment, but the greater volume of fine-grained sediment interbedded with these sands suggests deposition occurred as the river channels and the bedrock valleys beneath them became more completely alluviated. This may have occurred in response to a slackening river gradient, perhaps marking a transition to a Lincolnia-style floodplain and backswamp.

Lincolnia silty clay (**Kpl**): This member forms the surface of the Potomac Formation over a large area in the western part of the city and adjacent jurisdictions, where it holds up numerous slopes and bluffs. The majority of this area is covered by late Tertiary sediments of the Dowden terrace and younger *colluvium*, so most information about the unit comes from excavations and engineering borings. The portion of the outcrop area in the Lucky Run drainage is strongly dissected, creating a few hillside exposures. But the Lincolnia silty clay is generally not a strong outcrop maker, and most of the area it occupies is heavily urbanized, so most natural exposures are small and principally limited to the beds of a few natural ravines. The best extant exposure of the unit (#155) is in the head of an unnamed ravine in Chambliss Park, less than 100 feet below the dead end of Scott Street, in the northwest part of the city. Other good exposures occur in the bed of Lucky Run in the Stonegate Scenic Easement downstream of Braddock Road; in the bed of the ravine at Winkler Botanical Preserve; and in an unnamed ravine below Crown Royal Street in Oakwood, Fairfax County. Larger exposures were observed in several excavations open during the course of fieldwork for the atlas, including the type locality (exposure #64).

In ravine outcrops, the predominant lithology is massive to slabby-looking, greenish-gray to tan, clayey silt and silty clay (figure 4-14). A bluish-green caste is typical in excavations below the water table. Most of this unit, however, occurs in heavily weathered parts of the landscape adjacent to the Dowden Terrace, and typically exhibits strong brownish red colors; green *mottles* are commonly present where a *perched water table* is present (figure 4-15). Regardless of the degree of weathering, most samples contain a noticeable amount of "grit" when hand textured, giving the material the feel of a silty clay loam; particle size analyses of two samples indicate a texture between silty clay loam and clay loam (figure 4-7). Most large exposures show regularly spaced, steeply dipping joints.

Figure 4-14. Left: The typical greenish-tan caste of less-weathered Lincolnia silty clay, as seen at the Chambliss Park exposure. Regularly spaced, near-vertical joints produce the somewhat rhombic shaped edges in the exposure. The pale color contrasts sharply with the brownish-red color of strongly weathered exposures (right), such as this sample from an excavation at Utah Street Park in South Fairlington. The two exposures differ little in particle size (figure 4-7), but the enhanced weathering evident at the Utah Street site is expressed by a vastly greater kaolinite content (figure 4-8). Photos by Tony Fleming.

Primary sedimentary structures are very difficult to recognize, especially in the massive variety, which often looks completely unstratified. Stratification is more readily evident where thin (a few inches or less) sheets of fine and medium sand are present with the silty clay in outcrops. Some of the slabbier-looking material contains hints of a fine, planar lamination and an incipient *fissility*, presumably developed parallel to lines of stratification. Thin lignitic material is sometimes seen when the sediment is split open along the fissility.

Small to medium sized bodies of clayey, arkosic, *medium sand* are present locally in the Lincolnia silty clay, as observed in a few exposures and reported in a moderate number of engineering borings. Most of these bodies are less than 5 feet thick and rarely extend more than a few tens or hundreds of feet laterally, judging by their limited distributions at the larger geotechnical sites. Substantially larger sand bodies are present close to contacts with both the Winkler sand (Kpw) and the upper Cameron Valley sand (Kpcv), and in some vertical sections, it is often quite difficult to determine where one member stops and another begins. At other sites, however, the base of the Lincolnia is in sharp contact with the underlying Cameron Valley sand (figures 4-15, 4-16), with little or no interbedding of the two lithologies. At these places, the Lincolnia appears draped over the underlying sand, filling in small hollows and irregularities.

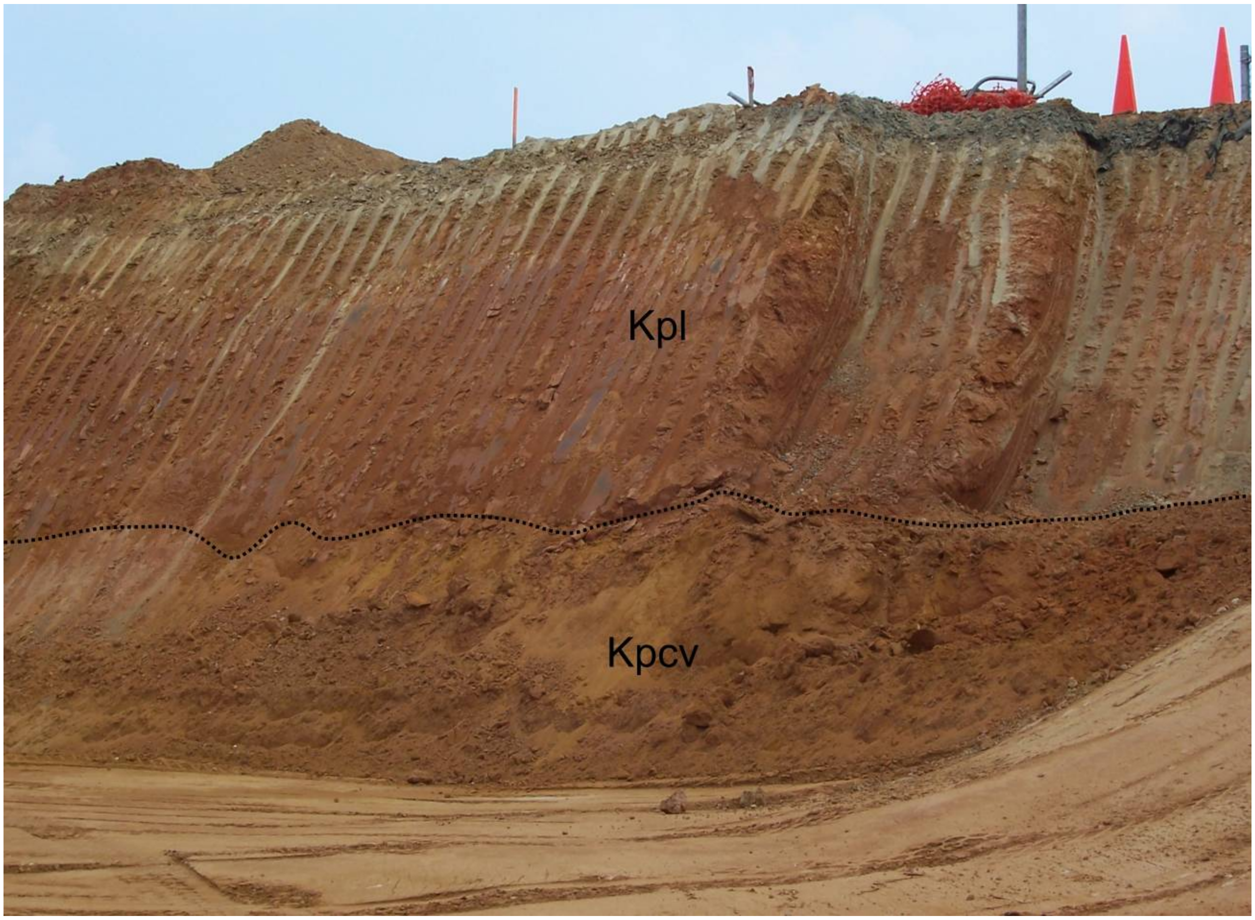

Figure 4-15. Gummy, moist, green and red mottled silty clay (Kpl) just above its contact (dotted line) with the Cameron Valley sand (Kpcv). Excavation at King St x George Mason Dr. Photo by Tony Fleming.


Figure 4-16. Sharp basal contacts of the Lincolnia silty clay. Left: The contact between slabby-bedded Lincolnia silty clay above, and softer, cross-bedded Cameron Valley sand below forms a small cascade in an unnamed ravine in Oakwood, Fairfax County. Right: The contact is well defined by texture and color changes, and by a thin layer of purplish, ferruginous sand (visible just below knife) in this strongly weathered exposure in a large building excavation adjacent to Dowden Terrace. Photos by Tony Fleming.

The thickness of the Lincolnia silty clay is about 40-60 feet in many places, but it varies considerably in response to broad undulations in the elevation of the basal contact with the underlying Cameron Valley sand, ranging from as little as ten feet in some geotechnical borings to 100 feet or more below parts of Fort Ward Heights and Lincolnia. At other places, parts of the Lincolnia section are cut out by large, wedge-like bodies of Winkler sand.

N values reported in geotechnical borings are typically high in the Lincolnia silty clay, indicating a very stiff to hard consistency. The unit appears to be fractured throughout and exhibits well-developed, regularly-spaced vertical or near vertical *joints* in most exposures. Prominent *oxidation haloes* along the joints and a brownish-green mottling of the blocks between the fractures were observed in two large excavations below the water table, one adjacent to Shirley Highway in Lincolnia (exposure #64, the type locality), and the other in a hillside behind the NVCC parking garage on North Beauregard Street (exposure #9). The joints facilitate vertical movement of oxygenated ground water downward into the clay, enhancing the depth of the weathering profile.

The Lincolnia silty clay forms a prominent *confining unit* over the Cameron Valley sand wherever it is present, locally separating the lower Potomac *aquifer* from the overlying Winkler sand. The relatively poorly permeable Lincolnia undoubtedly is responsible for the *perched water table* that is commonly observed (or reported in borings) in the overlying Winkler sand. The network of fractures and thin sand seams in the unit promotes some ground-water circulation, however, because the unit frequently appears moist in exposures, with ground water visibly seeping from open fractures, and it is often described as “wet” in geotechnical borings. In a few cases where borings that terminated in the Lincolnia were left open for 24 hours or more, a water table was usually reported prior to boring closure, presumably the result of inflow from fractures or thin sand seams.

The Lincolnia silty clay also appears susceptible to landsliding, and bluffs developed on it typically exhibit scars from prehistoric and modern slope failures. An excellent example may be seen along the west side of North Van Dorn Street between Holmes Run Parkway and Landmark Shopping Center (exposure #11). In many geotechnical borings, the unit is described as “fissured” or “slickensided”, attesting to its instability, and less weathered parts of the unit are invariably classified as “*fat clay*” (CH) or “elastic silt” (MH), reflecting a preponderance of expandable clay minerals. The clay fraction from the less weathered sample in table 4-2 contains 78% expandables, which probably represents a minimum percentage likely to be present in the original, unweathered material.

Plant materials are locally reported from the Lincolnia silty clay in engineering borings. These are most commonly described as *lignite* beds, wood, and leaves. As far as known, none of these occurrences have ever been identified or described in detail. Hueber (1982) mentions a robust macrofossil assemblage from the Shirley Highway site and speculated that such assemblages are probably fairly common but largely undiscovered. The accompanying *microfossils* at the Shirley Highway site yielded a clear correlation to other early Cretaceous floras and to Hickey and Doyle’s (1977) zone 1 (lowermost Potomac Formation), thus providing the best control yet on the age of the formation in Alexandria. Together with the sedimentary characteristics of the deposit, Hueber (1982) interpreted the Shirley Highway flora as being indicative of a *backswamp* environment of sedimentation.

The overall character of the Lincolnia silty clay, along with its conformable basal contact with the lower Cameron Valley sand, and probable lateral facies relationship to higher intervals of the Cameron Valley sand, support an origin as *overbank* sediment deposited on a broad, stable *floodplain* that developed when the active river channels that deposited the underlying Cameron Valley sand began to be abandoned and(or) began migrating some distance away from the map area. The thin, highly localized bodies of sand reported in some borings are probably *crevasse splays*—arcuate to fan-shaped sand sheets deposited on the floodplain surface adjacent to breaches in natural levees. The existence of a sharp basal contact with little interbedding in some sections, versus complexly interbedded sand and silt in others, may indicate fairly abrupt abandonment of channels and transition to a backswamp environment at some sites, while river channels persisted for longer periods at others. The appearance of the Winkler sand, however, indicates the re-establishment of channel conditions at some point during Lincolnia sedimentation. Relations to other map units are not so clear: as far as is known, the Lincolnia silty clay appears to be restricted to the western half of the city. Along Four Mile Run Valley, it could not be traced eastward beyond Parkfairfax; there, it becomes indistinct among the heterogeneous sediments of the Chinquapin Hollow member, and on the north side of the Cameron Valley, it appears to be cut out by the massive Arell clay near Dalecrest.

Barcroft diamicton (**Kpb**): A completely different and exceptional lithology—the Barcroft *diamicton* (figure 4-17)—occurs at scattered places near the base of the Lincolnia silty clay. The diamicton is named for exposures in a stormwater gully at Barcroft Park in southern Arlington County, directly below Claremont Elementary School (GTB-112, **plate 1**).

Figure 4-17. The Barcroft diamicton at its type locality at Barcroft Park in southern Arlington County. The "striped" appearance is created by alternating bands of brown loam, green-gray clay loam, and dark silty horizons containing disseminated organic matter and wood fragments. All three types of layers tend to be very hard and all contain evenly distributed gravel, cobbles, and boulders up to 18 inches in length. The clasts consist entirely of quartz-rich varieties, primarily vein quartz, quartzite, and sandstone, and closely resemble the upland terrace gravels. Some boulders contain prominent Skolithos trace fossils, indicating that they were derived from late Cambrian Antietam Sandstone from the Blue Ridge. Some clasts are moderately well rounded, but many others have markedly flatiron shapes, and some have pitted surfaces. The layers in this exposure superficially resemble bedding, but the clasts do not always occur in organized beds or lenses. They are just as likely to be evenly dispersed within the fine grained matrix, or form random pockets.

Photo by Tony Fleming.

The diamicton at Barcroft Park is about 18 feet thick, and overlies interbedded sand and hard silty clay of the upper Cameron Valley sand, and is in turn overlain unconformably by intensely oxidized late Tertiary gravel that caps the Chinquapin Village terrace (**plate 5**). Initially, the diamicton was considered to potentially be a basal facies of the terrace gravel, but outcrops of similar diamicton (figure 4-18) were subsequently observed in two other places where it is unequivocally enclosed within the lower part of the Lincolnia silty clay: Lucky Run in Stonegate easement, from about 150-400 feet below Braddock Road (exposure #78); and an unnamed ravine below Crown Royal Street in Oakwood (exposure #164), where the diamicton forms a prominent cascade along the creek. At both of these locations, the diamicton is clearly interbedded with typical Potomac Formation lithologies, chiefly green-gray silty clay, and lesser fine clayey sand.

Figure 4-18. The Barcroft diamicton along Lucky Run in Stonegate Scenic Easement (left) and along an unnamed ravine in Oakwood (right). A sample from the Lucky Run exposure yielded a loam-textured matrix (figure 4-7) with a relatively kaolinite-rich clay mineralogy (figure 4-8). Both exposures are far from any terrace gravels and are demonstrably within the lower part of the Lincolnia silty clay. Photos by Tony Fleming.

The origin of the diamicton is speculative. There is no evidence of glaciation; none of the material exhibits striations or the internal fabric characteristic of glacial till, nor is it associated with other deposits normally found in glaciated areas, such as well-sorted gravelly outwash or laminated lacustrine deposits. Instead, it occurs within the Lincolnia silty clay—a backswamp deposit with a flora characteristic of a warm-temperate climate. The diamicton could represent *debris flows*, but that does not adequately explain either the faceted shapes of many clasts or the repetitive horizonation and gleyed appearance of some of the matrix, nor is it clear how a backswamp environment could provide the topographic relief necessary to drive debris flows. An alternate explanation might be a stranded bar, or lag, of extremely coarse clasts that were left behind after a high energy flood winnowed out all of the fines. Subsequently, the area was abandoned by any active river channels, leaving the bar as a weathering surface that was exposed to the elements for millenia, producing *ventifacts* (wind shaped clasts). The abundance of kaolinite and chlorite in the clay fraction supports the idea of intense weathering during deposition. In this hypothesis, the matrix may represent a series of *accretion gleys* (c.f., Follmer, 1982, 1983) that accumulated very slowly, perhaps as dust or fine-grained backwater deposits that became trapped in the large voids between the clasts. The water table may have been sufficiently close to the surface in this environment (presumably an alluvial plain) to produce the gleyed colors and to prevent organic matter, such as wood, from being oxidized and destroyed.

Winkler sand (**Kpw**): The Winkler sand is named for the sharp, fin-like ridge adjacent to Shirley Highway along the east side of the Winkler Botanical Preserve. The hillsides of this dry ridge are sandy and acidic, and support a forest of stunted chestnut oak, mountain laurel, and other heaths. This unit forms a series of small to medium-sized bodies concentrated in a northeast-trending belt that generally parallels Shirley Highway from Lincolnia to Parkfairfax. The distribution of these bodies is largely deduced from a combination of the excellent geotechnical borings on and near Shirley Highway, landforms, sandy soil, and remnants of acidic sand forest. Exposure is poor in this highly urbanized corridor, the best being in tree topples on the hillsides in the botanical preserve, an old cut on the steep hillside above a parking lot on the west side of Beauregard Street (exposure #38, an old, steep cut on the west side of South Reynolds Street (exposure #84), and a roadcut (now covered) at Buzzard Gap (figure 4-19).

Figure 4-19. The Winkler sand at Buzzard Gap, circa January, 2007. The face consists of medium sand with planar cross beds. Photo by Rod Simmons.

The characteristic lithology is medium to coarse, well-sorted, arkosic quartz sand, plus or minus quartz pebbles. Some strata are described as gravel in a few geotechnical borings, mainly along Shirley Highway. Most of the Winkler sand occurs at elevated locations in the landscape that have experienced prolonged weathering, so most of the feldspar is weathered to silt and clay. Both samples analyzed for this study (figures 4-7, 4-8) were strongly weathered loams from high in the regional landscape, with much or all of the original expandable clay converted to kaolinite.

Sedimentary structures are poorly known. Medium-coarse clayey sand with northeastward dipping planar cross beds could be discerned at the Beauregard Street locality, but the degree of slumping and weathering precluded more detailed observation. Similar features were inferred from the slumped exposures on the steep hillside north of Fort Reynolds (exposure #46) in South Fairlington. A clean face in an excavation near Beauregard and Armisted Streets (exposure #36) exposed about 8 feet of medium-coarse sand with planar cross-beds similar to those in figure 4-19, showing a strong northeasterly current vector.

The map pattern suggests that the individual bodies of Winkler sand formerly comprised a unified, southwest to northeast trending, wedge-shaped mass of sand prior to Pleistocene incision, with its central axis roughly parallel to Shirley Highway. The Winkler sand does not appear to have great lateral extent; it could not be traced east of INOVA hospital, where its thin edge appears to be cut out by the Arell clay, nor east of South Fairlington, where it blends into the diverse sediments of the Chinquapin Hollow member.

At most places, the thickness of the unit is between 30 and 50 feet, but it may be more than 75 feet at a few places along its central axis. The origjnal thickness in that area could have been greater, however, but ultimately is unknown since the unit is truncated by late Tertiary erosion along the bases of the Dowden and Chinquapin Village terraces. The Winkler is deeply incised into the Lincolnia silty clay, and in at least one location, into the underlying Cameron Valley sand: the body mapped in the vicinity of Beauregard and Armisted Streets, above the west side of Holmes Run, has cut completely through the Lincolnia silty clay. This relation can be seen in the set of geotechnical borings at that site (#2), and indicates that the Winkler has coalesced with the underlying Cameron Valley sand to produce a very thick composite sand section in that area. A similar relation may occur at places along Shirley Highway between King Street and Four Mile Run, but the evidence is more inferential.

The Winkler sand marks the (re)establishment of an active river channel or channel system on the Lincolnia floodplain. It is entirely possible that the channel(s) in which the sand was deposited may have even been contemporaneous with the upper part of the Lincolnia silty clay, though evidence bearing on this question is scant. In any event, the coarse, pebbly Winkler sand probably formed as a stack of transverse bars in such a channel.

Figure 4-20. Ferruginous crust from a seepage face in the Winkler sand, just above its contact with the Lincolnia silty clay at Hospital Woods. Such crusts are commonly called "bog iron" because of their ubiquitous occurrence in springs and other ground-water-fed wetlands. The hard, purple cementatious material is hematite. Photo by Tony Fleming.

The Winkler sand forms a locally important aquifer, and is frequently reported to have a perched water table developed in it at geotechnical boring sites. Springs discharging from this unit appear to be the source of water for several perennial ravines, including those at two important natural areas in the city: the Winkler Botanical Preserve, and the ravine at Hospital Woods. The unit also crops out in a narrow strip along the slope at Seminary Woods, thus accounting for the abrupt appearance of a sandy, acid soil and corresponding natural community there. Ground water discharging from the Winkler sand along its contact with the underlying Lincolnia silty clay has locally caused it to become cemented by purplish-red hematite, producing characteristic slabs of "bog iron" that mark the trace of the contact along hillsides (figure 4-20).

Chinquapin Hollow fine sandy clay (**Kpch**): This member occupies most of the northeastern quadrant of the highlands, and is named for exposures in Chinquapin Hollow, where the whole suite of lithologies that comprise the unit can be seen in a compact area. In some ways, this is a "default" map unit in that it is defined as much by the area it underlies as by lithology. And, from a geological standpoint, both the area and the map unit are the most poorly defined of any area or named map unit in the city. Outcrops are confined to a few relatively natural ravines, the largest of which are upper Taylor Run (Chinquapin Hollow), Timber Branch, the stream in Monticello Park, and an unnamed ravine west of Russell Road below St. Agnes School. Engineering borings are sparse, and most are less than about 35 feet deep—barely enough at most places to extend through the younger river terraces capping the upland surfaces in this area. The limited data are compounded by the marked heterogeneity of the sediments exposed in outcrop, which typically include almost every combination imaginable of sand, silt, and clay in a single stream exposure. If anything, this map unit is defined by its considerable lithological variability.

Figure 4-22. Characteristic color banding, or variegation, in a typical exposure of the Chinquapin Hollow member at its type locality along Taylor Run. The brown bands are layers containing slightly more sand than the greenish layers. Photo by Tony Fleming.

The most common lithology appears to be very fine sandy clay interbedded on a fine scale with clayey fine sand and silt. The sediments are typically greenish-gray to buff-colored, plane bedded, and locally striped, or variegated, in earthy tones (figure 4-22). In some cases, the variegations appear to be caused by slight differences in the sand content between adjacent beds, which result in modest permeability contrasts that cause sandier beds to be oxidized while adjacent, less sandy layers remain in a reduced, or gleyed, state. In others, however, reddish partings of silt and clay separate green-gray beds of clayey sand. The largest beds are seldom greater than about 2 or 3 inches thick, and some appear to be graded. Some of the exposures in Chinquapin Hollow and Monticello Park also appear to consist of repetitive, subtly fining-upwards sequences, with each bed consisting of fine clayey sand at the base and sandy silt or sandy clay at the top, with thin silt-clay partings separating the beds (figure 4-23). Some sandy beds exhibit planar cross stratification.

Figure 4-23. Thin, repetitive, planar beds of clayey fine sand, separated by partings, or drapes, of reddish silty clay. Some of the sand beds immediately below and to the left of the coin appear faintly cross bedded. Chinquapin Hollow. Photo by Tony Fleming.

These vaguely laminated-looking sections are typically interbedded with several other lithologies, the most common of which are massive, green-red mottled silty clay and clayey and silty fine sand (figure 4-24); gray, elastic organic silt is also present in some outcrops along Taylor Run. In outcrop, these bodies are invariably less than a few feet thick, are sheetlike or lenticular in shape, and seldom have more than a few feet of lateral extent. It is often difficult to visually distinguish the clayey sands from sandy clays, and all three types frequently grade into one another. Scattered lenses of granule sand or fine pebbles also occur sparingly. Lignite, wood fragments, leaf impressions, and disseminated organic matter (typically found in the silts) are all abundant at places in the unit.

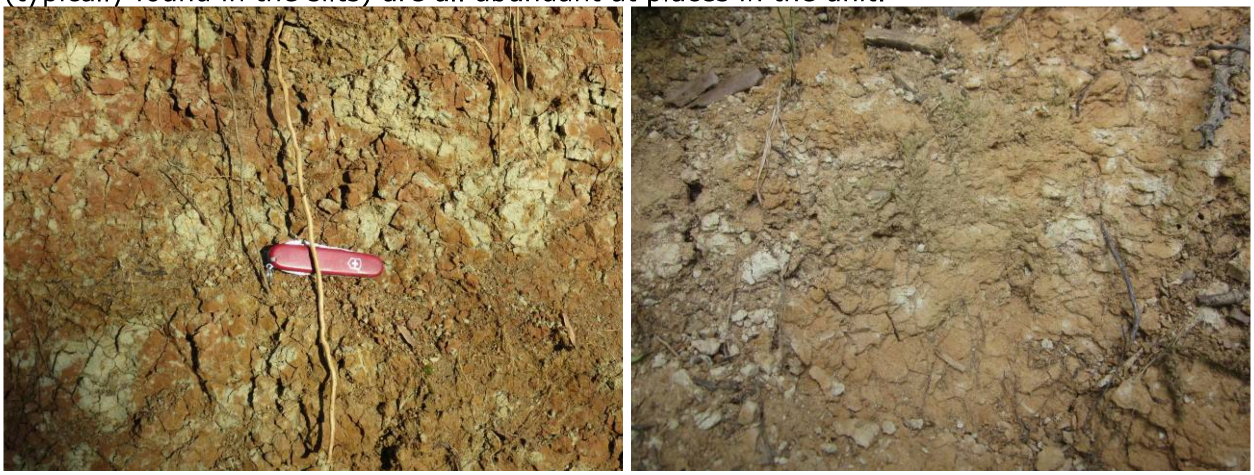

Figure 4-24. Small bodies of silty clay (left) and clayey sand (right) are common in outcrops of the Chinquapin Hollow member. They can look deceptively alike, as both tend to be mottled and jointed. Photos by Tony Fleming (left, at Monticello Park) and Rod Simmons (right, at Goat Hill Park).

Several larger bodies of sand (Kpch-s) and massive silty clay (Kpch-c) can be recognized in scattered outcrops and geotechnical boring sites in the Chinquapin Hollow member (figure 4-25). None of them can be traced much beyond a single site because of limited outcrop and poor subsurface control. The largest such sand body known is from geotechnical borings near Aspen Street and Russell Road (site #'s 147 and 176), and is at least 45 feet thick. Another sand body known from outcrops in a ravine below St. Agnes School may have a similar thickness.

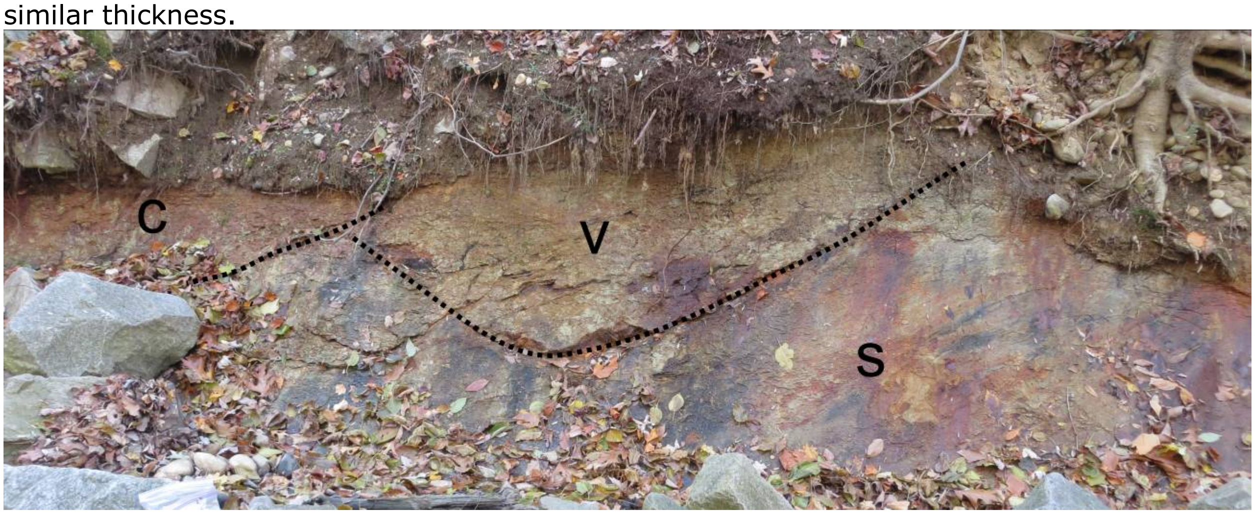

Figure 4-25. Larger bodies of fine-medium sand (S) and gummy silty clay (C), some apparently several tens of feet thick, are interbedded with the typical variegated material (V at some outcrops and geotechnical sites, but are generally not traceable over any great lateral extent. Face is about 20 feet wide. Chinquapin Hollow. Photo by Tony Fleming.

Texturally, there are only modest differences among the different kinds of beds that make up the typical variegated lithology (table 4-1; figure 4-7). The sandier beds are loams and clay loams, while the less sandy ones are silt loams and silty clay loams. Only the larger sand bodies stand out on the textural triangle (figure 4-7), being fine sandy loams.

The heterogeneous assemblage of sediments that comprise the Chinquapin Hollow member may represent a medium-energy floodplain that developed on the surface of a large point bar. The graded, upward-fining sequences are suggestive of individual flood events. Each event caused the bar to accrete vertically. The larger sand bodies may be localized secondary channels that developed on the surface of the bar, whereas the thicker silty-clay beds may be plugs filling some of those same channels after they were abandoned. The prevalence of gleyed colors, along with the presence of wood, cypress needles, and abundant organic matter, implies a frequently wet or waterlogged soil, which is consistent with a low surface not far above water level, such as a broad, low-lying point bar. Alternatively, the entire unit may simply represent a broad, linear floodplain surface marginal to a river channel, but a point bar origin is more appealing in terms of the geometric relationship of this unit to the Arell clay, as outlined in the next section.

The thickness of the Chinquapin Hollow member is not known because its base is nowhere exposed in outcrop or defined by boreholes, while its upper surface is truncated by erosion. The apparent thickness is at least 120 feet, based on the fact that the lowest known outcrops of the unit occur at an elevation of about 60 feet, while the highest part of the unit as defined by a few boreholes at TC Williams high school is at an elevation of almost 180 feet. This estimate, however, does not take into account the overall tectonically-induced dip of the Potomac Formation, which is difficult to determine at this horizon given the lack of definitive stratigraphic markers. Assuming the unit occupies the entire elevation differential of the massive Mt Ida scarp above Del Ray, and considering that the base of the unit at that location probably lies at an elevation significantly less than 60 feet, then 120 feet is an entirely reasonable minimum thickness.

The relationship of this unit to the Cameron valley sand, Lincolnia silty clay, and Winkler sand is obscure. The map pattern in the vicinity of Parkfairfax and South Fairlington suggests that the Chinquapin Hollow may unconformably overlie these units, but a large-scale facies change to the Winkler sand also is a possibility. Relations are especially obscure adjacent to lower Four Mile Run, where the unit appears to be in contact with the upper part of the Cameron Valley sand over the thalweg of the buried bedrock valley. There, it is conceivable that the entire sequence could simply be part of a large valley fill that grades up from coarser channel sands at the base, through the increasingly silty interval of the upper Cameron Valley, and into the finer grained floodplain deposits of the Chinquapin Hollow. It also seems likely that the unit extends beneath the Old Town terrace below Del Ray, based simply on its geographic proximity, but a near complete lack of deep subsurface data for Del Ray makes such an interpretation speculative. Obviously, less is known about all these relations than is known, and a substantial amount of new subsurface and outcrop data is needed before a satisfactory interpretation can be worked out.

The Chinquapin Hollow sediments are the source of many small springs and seeps, which appear in abundance along just about any reach of stream where the unit is exposed. The unit is undoubtedly characterized by a complicated ground-water flow regime marked by multiple perched water tables and complex and unpredictable interfingering and cut-outs of more and less permeable strata. The unit is somewhat sandier than the Lincolnia silty clay and much sandier than the Arell clay and, therefore, might *appear* to be less subject to landslides and slope stability issues. However, the proportion of expandable lattice clay minerals approaches 100% in all of the Chinquapin Hollow sediments—consistently the highest of any member of the Potomac Formation (table 4-2; figure 4-8). That, coupled with the closely interbedded sandy and clayey strata, actually creates heightened potential for landslides and other stability issues, a fact vividly illustrated by numerous landslide scars and many sharply leaning objects on slopes that are clearly experiencing strong hillside creep.

Arell clay (**Kpa**): The Arell clay is a thick wedge of probable lacustrine sediment that underlies a large swath of the uplands between Shirley Highway and the Masonic Temple. This member is named for exposures in the steep bluff above Duke Street off the end of Arell Court, where it was first observed in a building excavation (exposure #201). In map plan, the clay forms an elongate body that extends from Shirley Highway to Old Town, with its long axis roughly aligned with Seminary Road and Janneys Lane.

The Arell clay is well defined in outcrop, subsurface borings, and geomorphically. This large mass of clay is responsible for some of the most rugged and elevated topography in the map area, including the imposing Hospital escarpment, the Seminary terrace and adjacent Fort Ward escarpment, and several other oversteepened bluffs of high relief further east. Dissected areas on the clay are characteristically marked by grades in excess of 35% and by long, steep hillsides that exhibit much evidence of past and present landsliding. Some scarps are near vertical where slopes have failed along steeply dipping fractures.

Texturally, the Arell member is clay (figure 4-7). Most samples contain greater than 50% clay (table 4-1; figure 4-7), with the rest being silt and very fine sand. In outcrop, the characteristic lithology is massive clay. Where unweathered, the clay is typically dark bluish-gray or greenish-gray in color, but within 10-20 feet of the surface, it is commonly mottled in brownish-red tones (figures 4-26 and 4-27).

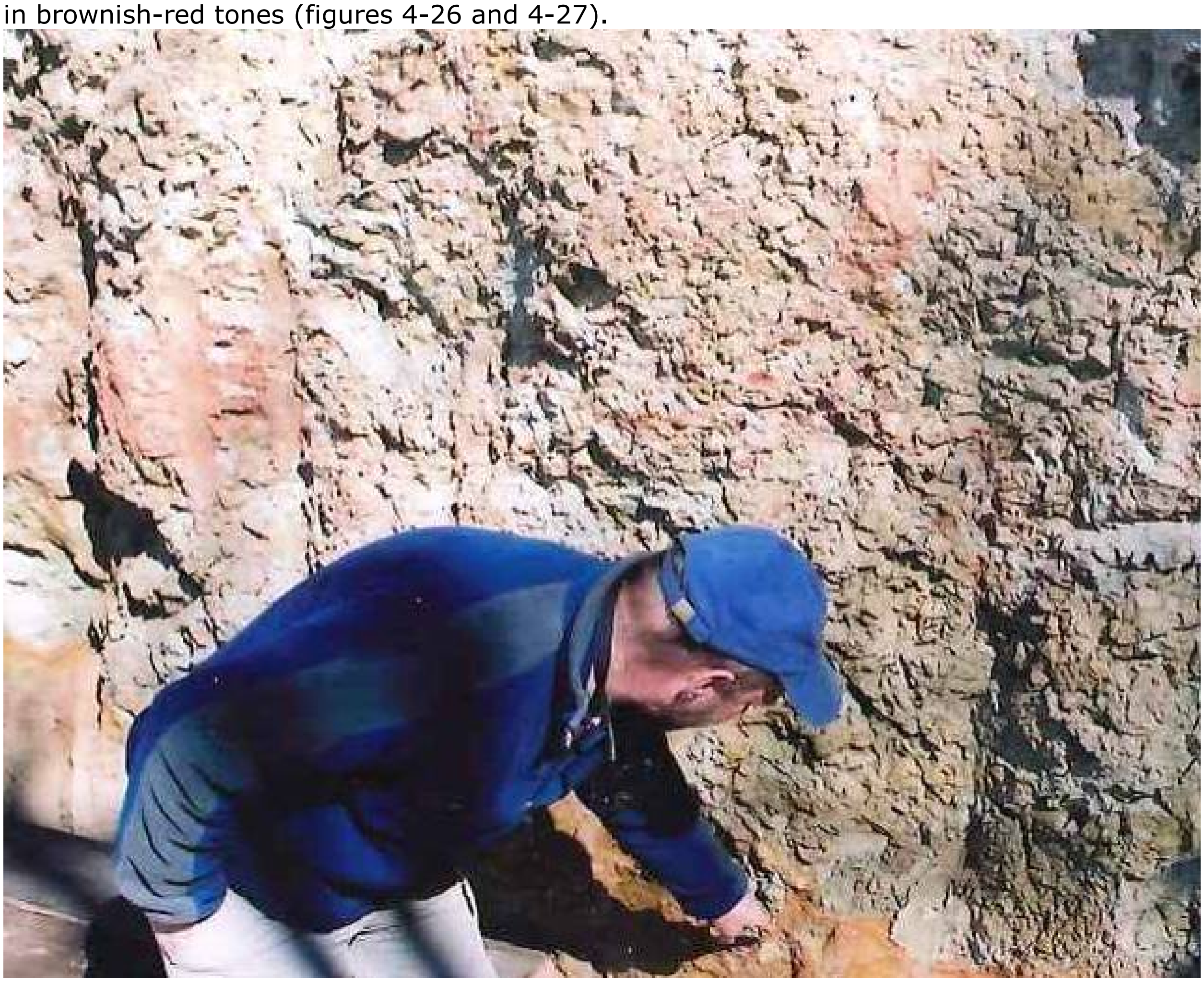

Figure 4-26. Greenish-gray, fractured clay with reddish mottled areas above, at the type locality on Arell Court. Many fracture surfaces are slickensided. Photo by Rod Simmons.

Figure 4-27. Strongly mottled Arell clay from the B horizon of a deep, remnant Tertiary(?) vertisol exposed on a hillside between Shooters Hill and Taylor Run. Numerous small fractures are visible, many coated with waxy-looking clay films, as well as several longer joints, most of which are steeply inclined to the right. Despite being close to the soil surface during the late Fall dry season, the clay was very moist and plastic when this image was taken. Photo by Tony Fleming.

The bulk of the unit contains little sand, either as discrete bodies or admixed into the matrix. Sample #'s 169, 296, and 306-B (table 4-1) are representative of the core of the unit and contain 15% or less sand, nearly all of which is very fine sand. Likewise, geotechnical borings seldom mention any sand in descriptions of the unit. Intervals of silty clay are more common and are typically somewhat lighter in color. Small sheetlike sand bodies are slightly more numerous near the edges and close to the base of the map unit, but are by no means common; their presence may help explain the noticeably higher sand content in the sample (#113) from the west branch of Taylor Run, which lies very close to the inferred contact with the much sandier Chinquapin Hollow member. Good examples of both massive and somewhat slabby-looking Arell clay can be seen in several exposures along the west branch of Taylor Run in Forest Park. Other good outcrops if similar clay occur for several hundred feet about halfway down the ravine in Clermont Woods Park in Fairfax County, but as noted elsewhere, a direct correlation with the Arell clay is uncertain.

Within the City, no definitive sedimentary structures have been observed in the clay, though some exposures on the west branch of Taylor Run exhibit a coarse, slabby layering that may be mimicking lines of stratification. South of Cameron Run in Fairfax County, however, several exposures of identical-looking clay that occupies the same stratigraphic interval within the Potomac Formation as the Arell exhibit very fine laminations (figure 4-28). No fossils of any kind, including wood or other plant material, have been observed in the Arell clay or reported from any borings.

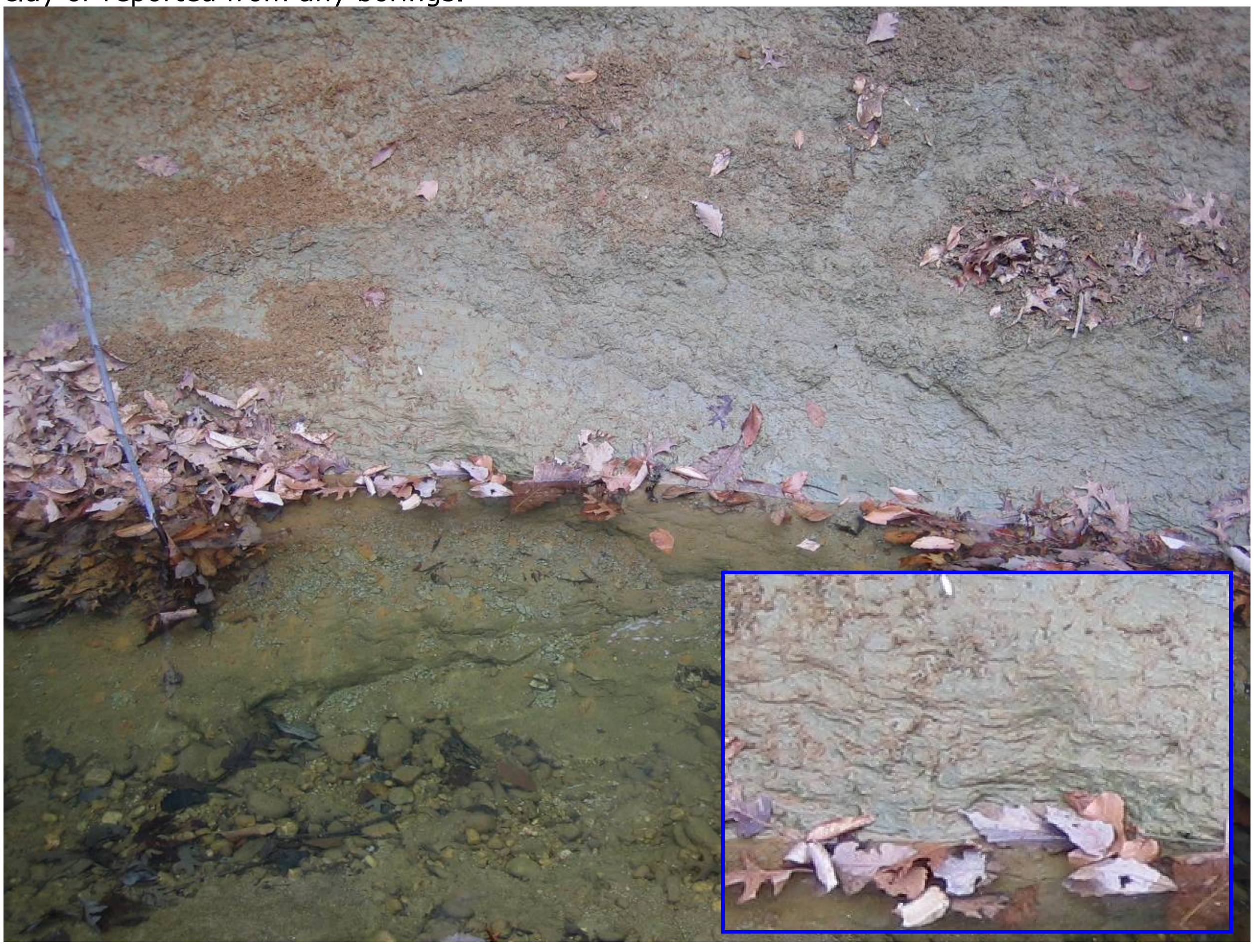

Figure 4-28. Green-gray clay in Clermont Woods Park, Fairfax County. The clay exhibits a strong fissility and possible laminations (inset). Although this area was not mapped in detail, the clay occurs along the same stratigraphic horizon as the Arell clay directly across Cameron Valley, suggesting they may be correlative. Photo by Rod Simmons.

The thickness of the Arell clay cannot be determined directly because its upper surface is truncated by post-Cretaceous erosion except for a small area beneath Shooters Hill. No single boring penetrates the entire extant thickness of the unit, but a combination of several boring sites, excavations, and outcrops located between the summit of Quaker Lane and Wheeler Avenue (below Duke Street) span the entire section and indicate that the clay is some 110-120 feet thick there. Not a speck of sand is reported within this interval in any of these borings. East of Quaker Lane, the base of the unit falls in elevation, while its upper surface becomes truncated by upland river terraces at progressively lower elevations, leading to a slight diminution of its apparent thickness in that direction. Data from water wells and geotechnical borings in the vicinity of the Masonic Temple, Federal Courthouse, and Capital Beltway/Rte 1 interchange indicate the base of the unit lies well below the floodplain surface of Cameron Run, and the total thickness may approach 200 feet. This value may come closest to representing the actual thickness, because the top of the clay is defined by the unconformable contact with the overlying Shooters Hill gravel member on the hilltop above the temple.

The Arell clay appears to unconformably overlie all the other members of the Potomac Formation except for the Shooters Hill gravel, although its relationship to the Chinquapin Hollow unit is equivocal. In the Hospital escarpment, the base of the clay is readily identifiable in outcrops and borings, and descends sharply eastward at an angle greater than the dip of the members below, cutting across the contacts between the Winkler sand, Lincolnia silty clay, and Cameron Valley sand. Near its western edge, the clay truncates the Lincolnia silty clay and Winkler sand. A large part of the northern margin of the body is in contact with the Chinquapin Hollow unit. The nature of this contact is difficult to interpret—along the west branch of Taylor Run, the clay is sandier than elsewhere and may be in a lateral facies relation to parts of the similarly sandy Chinquapin Hollow member—but the overall map pattern and cross-sectional profile of the clay suggest it is filling an asymmetrical, bathtub-like basin scoured out of all the other units, in other words, an abandoned meander. The main characteristics of the Arell—its massive appearance, dominant clay fraction, the near complete absence of sand bodies from large parts of the body, apparent lack of plant fossils, and its deep, channel-like shape—collectively suggest that it is a lacustrine deposit filling an *oxbow lake* that developed in a large, abandoned river channel at considerable distance from any active river channel(s).

It seems virtually certain that the Arell clay continues below the Old Town terrace, but its dimensions there are problematic to define with any degree of precision, due to the paucity of lithologic logs available for the many old, deep wells in the industrial part of town. Nevertheless, of the small percentage of geotechnical borings deep enough to penetrate beneath the Old Town terrace, most that report clay at top of the Potomac Formation are concentrated along a northeast-trending belt between Old Town and Potomac Yards (see "***Beneath Old Town and Del Ray***", below). If this interpretation is correct, the Arell clay may form a hook-shaped, or oxbow-like body that loops broadly around the Chinquapin Hollow member. Such an architecture is consistent with an origin of the clay as a lacustrine body that formed in a quiet oxbow after deposition of the point bar represented by the Chinquapin Hollow member. Small sheet-like sand bodies that occur sparingly near the northern margins of the unit could represent *crevasse splays* or sheet flood deposits that occasionally spilled into the edges of the oxbow during times of major floods on a distant channel.

The Arell clay is perhaps the most significant member of the Potomac Formation in the city, from both a geotechnical and geomorphic perspective. The consistency of the Arell clay ranges from very stiff to extremely hard. In geotechnical borings, the unit consistently exhibits some of the highest *N values* (75-100+) of any interval in the Potomac Formation, comparable to some of the densest sand units. Not surprisingly, the unit also appears to have considerable resistance to erosion, holding up some of the tallest, steepest bluffs in the region. Fractures are ubiquitous in outcrops (figure 4-29), and have been observed to occur in sets of widely-spaced, steeply dipping cross *joints*. The faces of the joints are locally coated by deposits of iron oxides.

As much as 81% of the clay fraction in the least weathered samples (e.g., #296, table 4-1) consists of expandable lattice clay minerals. Considering that this sample (and the Arell generally) is more than 60% clay, that means nearly 50% of the total sediment volume is expandable clay, leading to high shrink-swell potential and a typical designation as "*fat clay*" in geotechnical reports. The clay is typically described as "fissured" and "slickensided" in many of these borings—a consequence of the vertical motion associated with shrink-swell cycles (figure 4-29). Permeability is low and causes poor subsoil drainage—the clay is frequently noted as "wet" in borings, and outcrop samples have a pronounced plastic consistency when molded by hand. Not surprisingly, the unit yields only sparse amounts of ground-water discharge, resulting in ravines that are typically dry for much of the year.

Figure 4-29. The smooth face behind the 2 x 4 in this excavation parallels one wall of a steeply dipping joint. Large slickensides plunging toward the lower right are visible at several places on the joint surface. Photo by Tony Fleming.

These properties result in considerable instability of slopes developed on the clay: as noted earlier, virtually all of the steep slopes are dotted by prominent scarps that mark the heads of past failures, and one large landslide was in progress when the fieldwork for this project was conducted. In fact, it seems very likely that landslides have played the major role in the retreat of the major escarpments and general oversteepening of the slopes developed on the Arell clay. Due to the hard consistency of the material, slope failures tend to occur as coherent *rotational slump blocks*, although places where the clay had mostly liquefied into *debris flows* during failure were also noted.

Shooters Hill gravel (**Kpsh**): Little is known about this poorly exposed unit, which forms a small, erosional remnant between Ivy Hill Cemetery and Shooters Hill. The unit is almost entirely concealed beneath the younger gravel of the Beverley Hills terrace that caps this hilltop, and because of its superficial resemblance, it easily blends in with the terrace gravel. It probably would have gone unrecognized except for a combination of several small, superficial exposures, along with a few shallow geotechnical borings in which the thickness of the granular terrace sediment appeared anomalously large.

There are no clean, natural exposures of the Shooters Hill gravel. The unit is known only from a few surficial soil exposures on the upper slopes at the cemetery and Shooters Hill, a shallow archeological excavation (exposure #6), and descriptions from the bottoms of several shallow boreholes. The principal lithology is medium to coarse, silty and clayey sand with variable proportions of granules and fine gravel (figure 4-30). In borings, the sand is reported to be silty and dense—a characteristic of the Potomac Group—and is distinct from the overlying cobbly terrace gravel. The silt is likely derived from weathering of feldspar in the sand fraction, similar to other Potomac Formation sands. In surface exposures, the sand is yellowish brown, silty, and friable. At Ivy Hill Cemetery, the gravel fraction contains moderately well rounded pebbles of vein quartz and other siliceous types up to an inch long.

Figure 4-30. Surface exposures of the Shooters Hill gravel at Upland Park (left) and Ivy Hill Cemetery (right). Photos by Tony Fleming.

The current thickness of the Shooters Hill gravel appears to be less than 20 feet at most places, but is poorly defined, as most boreholes do not reach the base of the unit. At Ivy Hill, clay-rich soil more characteristic of the Arell clay appears on the hillside just below the exposure in figure 4-30, which would make the Shooters Hill gravel about 12-15 feet thick there. It probably is slightly thicker on the south side of Shooters Hill. The original thickness is unknown, because the top of the unit is truncated by post-Cretaceous erosion.

The significance of the Shooters Hill gravel to the local history of the Potomac Formation is not clear, due to its limited extent and exposure. It physically overlies the Arell clay, most likely along a local unconformity. It seems to represent the reestablishment of a more energetic river channel following the quiescent period represented by the Arell clay, but whether this was simply a localized feature or an environmental change of more widespread importance is unknown. From an environmental and ecological standpoint, the Shooters Hill gravel is likely to have soil-forming, hydrologic, and engineering qualities similar to those of the overlying terrace gravel.

Beneath Old Town and Del Ray

The lowlands adjacent to the Potomac River in the eastern part of the city are covered by thick *alluvium* of the late Pleistocene Old Town terrace. The alluvium is almost everywhere greater than 50 feet thick, and exceeds 100 feet in some places, putting the top of the Potomac Formation out of reach of the typical depths of most geotechnical borings. Of the hundreds of individual borings that have been made in the terrace, perhaps ~100 penetrate the upper part of the Potomac Formation. Most of these are located in Potomac Yards and at major building sites where the terrace alluvium is somewhat thinner, chiefly near the Federal Courthouse and along the Capital Beltway. The geotechnical borings are supplemented by rudimentary descriptions of several deep wells provided by Froelich (1985), consisting of the percentage of sand in each 100-foot interval penetrated by the well, and by one detailed formation log acquired by Johnston (1961) for a deep industrial well at the northernmost tip of Old Town. Collectively, these data are generally too few, too shallow, and too far between to allow the three-dimensional stratigraphy of the Potomac Formation to be worked out to a degree that might enable reliable correlation with the units mapped in the highlands to the west.

On the other hand, enough is known to indicate, in a general way, the gross composition (e.g., sand, clay, or a mix) of the Potomac Formation along its truncated upper surface beneath some parts of the Old Town terrace. This is particularly true beneath Potomac Yards, where a swath of borings several miles long and up to a half mile wide provides at least a limited picture. This evidence, coupled with the aforementioned descriptions from several deep wells, offers a tantalizing glimpse of what may be a very large body of clay that underlies most of southwestern Old Town and extends northeastward obliquely across Potomac Yards to the Potomac River. The part of the clay body below southwestern Old Town actually is reasonably well confirmed from several major building sites near the mouth of Cameron Run, where borings up to 100 feet deep penetrate a substantial thickness of hard, massive, *fat clay* beneath the younger alluvium. These sites are directly on line with the trend of the Arell clay in the adjacent uplands, and the clay in the borings can be traced directly into the Arell clay along the north side of Cameron Run Valley. The area where clay is consistently reported at the top of the Potomac Formation is indicated on **plate 4**.

Based on structural projections from the adjacent uplands, it can also be inferred that the top of the Potomac Formation beneath Del Ray is most likely composed of sediments belonging to the Chinquapin Hollow member, which fronts the adjacent Mount Ida escarpment. Nevertheless, for all the reasons outlined above, the interpretations of the Potomac Formation shown on plate 4 for a large part of Old Town and Del Ray must be regarded as highly speculative.

Paleo-Environmental Reconstruction of the Potomac Depositional System

The succession of strata in the Potomac Formation records multiple cycles of establishment, abandonment, and reestablishment of major river channels in the Alexandria area during early Cretaceous time. The earliest events, represented by the Cameron Valley sand, occurred when a major river system became established along the east- to southeast-dipping bedrock surface, initially occupying and alluviating major bedrock valleys. As the valleys became filled with sandy sediment, the channels migrated laterally, depositing sediment over other parts of the bedrock surface. These early channels probably had limited sinuousity, based on their lenticular shapes and a predominance of transverse bedforms with paleocurrent vectors consistently pointing down the slope of the bedrock surface, and probably interacted with irregularities on the bedrock surface. Abundant mica in some of the lowest strata suggests that the bedrock may have been deeply weathered by the time the channels became established. Once the bedrock valleys were largely filled, the channels probably migrated laterally with relative ease, because these earliest Potomac Formation strata lack appreciable volumes of fine-grained sediment, whose cohesiveness tends to stabilize stream banks and thus localize river channels in one place for long periods. The channels were probably choked with sand, producing a wide, braided alluvial plain.

A significant change in this regime appears to have occurred with the appearance of the Lincolnia silty clay. This sequence of fine-grained overbank sediment was deposited in a relatively low-energy floodplain and backswamp environment with a warm-temperate forest. The size and thickness of this deposit suggest that the floodplain was broad, long lived, and that deposition occurred at considerable distance from any large, active river channels. A few small sheet-like and channelized sand bodies within the unit probably represent a combination of crevasse splays and small auxiliary channels that were active during large floods, and perhaps, small alluvial fans deposited by tributaries that debouched onto the floodplain. Over the axes of the Cameron and Four Mile Run bedrock valleys, however, major river channels persisted well into "Potomac time", judging by the accumulation of thick stacks of sand bodies elongated in a down-valley direction in both places. Relations between the upper unit of the Cameron Valley sand, which accumulated in these channels, and the Lincolnia silty clay, which was probably marginal to them, are not entirely clear but suggest that the two units could be facies equivalents deposited at about the same time.

The regime changed again with the reestablishment of a moderate to high energy channel system on the Lincolnia floodplain, which is represented by the Winkler sand. Although subsequent erosion of this unit has left a fragmentary and possibly biased record, the map pattern along with sparse paleocurrent indicators suggest that the channel in which the Winkler sand was deposited trended northeasterly, as compared to the more southeasterly trends of earlier channels and sand bodies in the Cameron Valley sand. It is, of course, impossible to know how much of the Winkler sand has been stripped off, and whether the apparent northeasterly trend is simply an artifact of erosion.

The Chinquapin Hollow fine sandy clay marks a rather different environment than the earlier units. The predominantly fine- to medium-grained material of this unit may have been deposited over a long period of time on the surface of a broad point bar, or perhaps a marginal floodplain. The relationship of these sediments to the older units is obscure, but it seems possible that the Chinquapin Hollow is considerably younger than either the Cameron Valley sand or the Lincolnia silty clay, and could also be younger than the Winkler sand. An appealing hypothesis is that the Chinquapin Hollow unit formed on a large point bar during Winkler time, and grew on the inside of a very broad meander cut by a substantial river channel. Eventual abandonment of the meander and plugging of both of its ends by point bar sediment led to the development of a large oxbow lake in which the Arell clay was subsequently deposited.

The Arell clay is a thick mass of remarkably uniform, massive clay, in which there is little sand except along the margins. Such a body (in the context of the terrestrial setting of the Potomac Formation) almost has to be of lacustrine origin, and its deposition presumably spans a large period of time. What remains of this distinctive mass of clay is fragmentary, having been severely modified by Tertiary and Pleistocene erosion. It appears, for example, that a large part of lower Cameron Valley was excavated out of Arell clay. The body may well have extended significantly further westward, well past the present limits of erosion. An intriguing possibility, suggested by a few dozen geotechnical borings and deep wells, is that the clay may extend beneath Old Town in a *northeastward* direction, outlining a broadly hooked-shaped form that may define the axis of a large oxbow. If correct, such a feature would be of substantial scale—at least several miles long and some two miles wide. Perhaps not so coincidentally, the oxbow would outline the margins of the generally sandier sediments of the Chinquapin Hollow unit, encircling the southern edge of the original point bar around which the meandering channel developed.

The succession of map units in the city records an overall upward and eastward diminishing of grain size in the Potomac Formation, an observation consistent with trends observed in other places in the region. Whether this represents a change in sediment supply, a progressive slackening of regional gradients during Potomac time, or both, is not known. One possibility suggested by the types of sedimentary *facies* observed in the map area is that the basin may have become progressively filled, or alluviated, over time, thus transforming itself from a more robust, Piedmont-type system of discrete river channels into a broad, relatively flat alluvial plain. The abundance of cypress debris throughout the formation, but especially in the upper portions, implies that a relatively swampy environment persisted for much of the period. No evidence was found, however, which would suggest that any of this system was tidally influenced, at least not at this location.

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